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Selecting Sites for Monitoring Total Suspended Particulates

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by

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ABSTRACT

Criteria are suggested for locating high-volume total suspended particulate (TSP) measurement sites based upon sampling needs. These needs are determined and classified according to the purposes for which measurements are made. The first step in the site selection process is thus to identify the purpose of the monitoring and relate it to the size of the area for which the measurements are to be representative. Attention must also be given to particle size and the special requirements of monitoring the impacts of large, individual sources. A matrix is included to help the reader relate different purposes to appropriate spatial scales and to the other factors that are important to the site selection process.

Procedures are given for selecting locations that are representative of urban neighborhoods and interurban regions; selecting sites along traffic corridors is also discussed. Methods are also given for finding locations where the impact of major individual sources are most pronounced. The importance of smaller particles is emphasized because of their greater health and environmental effects relative to their mass. Specific recommendations for sampling heights, distances from sources, and placement relative to urban areas are given along with the rationale behind these recommendations.

PREFACE

The intent of this report is to provide a comprehensive and up to date technical resource document to assist EPA, state and local air pollution control agencies, and other users in developing better and more effective TSP monitoring networks. The information may be used by EPA in the future for developing more definitive guidelines and criteria for TSP monitoring. However, this report in itself does not constitute the official monitoring guideline of the Agency.

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SUMMARY

A review of air pollution literature reveals that atmospheric total suspended particulates (TSP) are collected and monitored for a wide variety of purposes. Furthermore, it is only seldom that any attempts are made to ensure that the location where the samples are collected matches the purpose of the sampling. Little has been done to classify the purposes of TSP measurement in such a way that a set of standardized station types can be proposed to meet the various purposes. The need for a set of uniform site definitions is certainly great. The costs of equipping the stations, the purchase or rental cost for housing the equipment, the servicing costs, and the data collection analysis costs can total many tens of thousands of dollars. If the site of the station is poorly chosen, most of this money could be wasted, especially if the data cannot be used for the intended purpose.

Most of the uses of TSP monitoring data fall into one of the following general categories:

- Evaluating compliance with air quality standards
- Determination of air quality trends
- Development and evaluation of control measures
- Public health studies
- Scientific research
- Miscellaneous

The preceding list of categories of monitoring objectives is based on the problems to which the data are relevant, but other systems of classification are also possible. In particular, we could classify the data according to what we want the data to represent. For instance, data that will be used to determine the effects of TSP on public health should represent the conditions in areas of public exposure. Data that are to be used to assess the impact of a single, large source should represent areas where the impact is most pronounced. If the classification of monitoring purpose is recast in terms of what the data should represent, then it will be much more closely related to the physical requirements of the monitoring sites.

The concept of spatial representativeness provides a useful basis for classifying stations and the uses for the data. Furthermore, the concept has a physical basis that can serve to define station characteristics. In general, the measurement scales that are of greatest importance are:

- Regional scale, to provide a measure of TSP concentrations typical of a large, usually rural area of reasonably homogeneous geography and that extends for tens to hundreds of kilometers.
- Urban scale, to define the overall, citywide conditions on a scale of tens of kilometers; in general, more than one site will be required for such definition.
- Neighborhood scale, defining concentrations within some extended area of the city that has relatively uniform land use; dimensions are of the order of kilometers.
- Middle scale, generally defining concentrations typical of areas with dimensions of tens to hundreds of meters. This category includes measurements to define concentrations along streets and roads; typical areas can be elongated, measuring tens of meters by hundreds of meters or even kilometers. Evaluating the effects of many kinds of fugitive dust sources can also fall in this category.
- Microscale, to define concentrations in volumes with dimensions of the order of meters to tens of meters.

Of course, the concept of scale can be extended to include the global scale, but for this discussion, those scales enumerated above are sufficient. In fact, the discussion emphasizes the neighborhood, and regional scales. Urban scale conditions, as noted, cannot be specified with measurements at a single location, but can be synthesized from measurements representing neighborhood scales. When the neighborhood scale is well represented, it will not be necessary to find the ideal urban scale site.

The microscale is not considered in detail in this report for several reasons. The most important of these arise because the emphasis is on the standard high-volume sampler method of measurement, which requires that the samples be collected over extended time periods-- usually 24 hours. An average over such a time period has a temporal resolution that is inconsistent with a microscale spatial resolution. The temporal variability that matches the spatial variability that one seeks to define with microscale measurements will be totally obliterated with 24-hour sampling. Other reasons exist for not proposing criteria for microscale measurements. For instance, such measurements are often made for very specialized research purposes that make a generalized set of siting requirements nearly impossible to devise.

The middle scale is not emphasized for reasons similar to those cited above for excluding the microscale. The inconsistency of the spatial and temporal scales applies. The primary air quality standards are based on health effects and apply to 24-hour or annual periods. Exposure on these time scales will generally involve areas much larger than the middle scale. Secondary standards are most applicable to visibility reduction, which is a phenomenon that usually manifests itself on scales larger than the middle scale.

Some TSP monitoring does not fit readily into any of the different classes of spatial representativeness. Cases exist where the samples are collected to determine the impacts of some large individual source of particulates--elevated sources are especially frequent objects of such monitoring. Although the scale to be represented will usually be the neighborhood scale the methods used to locate these "source- oriented" sites are so suffiently different they require a separate category, outside the categories devised solely on the basis of spatial representativity.

The most important basis for air quality standards is the public health impacts of a pollutant, which leads to one further consideration in the classifying of TSP monitoring sites and in the derivation of physical criteria for those sites. For monitoring purposes related to air quality standards or the evaluation of health effects, the sites should be located so that they portray public exposure reasonably realistically and so that the samples are also representative of those particulates that are the most damaging to human health. Studies have shown the smaller particles--with diameters less than a few microns--to be more respirable and a greater health hazard. The high-volume sampling method prescribed for measuring TSP to assess compliance with air quality standards emphasizes the larger particles. Mass per unit volume is measured. Since the mass of a single 10 μm particle is equal to that of a million 0.1 μm particles, the larger particles are weighted by the measurement method in a fashion inconsistent with their health effects. The smaller particles also have more pronounced effects (per unit mass) on visibility, attenuation of solar radiation, and cloud condensation processes than do the larger particles. Inasmuch as the prescribed sampling methodology emphasizes larger particles, which could be misleading for some monitoring purposes, the siting process should try to minimize such effects whenever appropriate.

Factors other than scale of representativeness, source evaluation requirements, and particle size are important to the definition of the required characteristics for the different types of monitoring site. One of these other factors arises because virtually all routine TSP monitoring is related directly or indirectly to health or public exposure and, therefore, samples taken at breathing level are most appropriate. Inlets at breathing level will constitute an obstacle in many locations and will also be subject to vandalism. It has been suggested that a height of 2 m is a reasonable compromise between these two conflicting requirements. Obviously, the sampler cannot always be placed exactly 2 meters high. If it is between about 2 meters and 15 meters high, and if it is well removed from any nearby source, the breathing zone concentrations will be reasonably portrayed.

The adoption of uniform criteria for locating air quality monitors would provide a consistency not now found in available data. Consistency will allow data from different locations to be compared with the assurance that differences in the data sets will reflect something other than anomalous site characteristics. In suggesting siting criteria for TSP monitors, an attempt has been made to maintain consistency wherever possible with other site classification schemes, especially those developed at the 1976 EPA Siting Workshop and those of Ott (1975) and Ludwig and Kealoha (1975). The latter authors have focused on the problems of carbon monoxide monitoring so that some unique differences relative to TSP siting will be inevitable, but they are few and not serious.

In proceeding from concepts such as spatial representativity or emphasis on different particle size ranges to a set of concrete siting requirements, some decisions are required; these decisions are made easier if they can be translated into very simple quantitative terms. The most pervasive of the translations that were used provided equivalence between the contribution that a specific source makes to observed concentrations at a monitor and the distance to that source. From this relationship, maximum allowable contributions (in $\mu g\ m^{-3}$) could be converted to minimum separations (in m) between the monitor and certain kinds of sources. For instance, regional sites should be far enough removed from cities so that the concentrations arising from emissions within the city will be less than five percent of the secondary NAAQS, or less than 3 $\mu g\ m^{-3}$. Similarly, neighborhood sites should not be so close to large sources that the emissions from those sources increase measured concentrations more than about ten percent of the primary annual standard, or 7.5 $\mu g\ m^{-3}$. Among the sources of TSP in urban areas is the street dust raised by traffic. Examination of collected samples (e.g., Draftz, 1975) has shown the presence of large amounts of such material, so samplers must be separated from nearby roadways if they are to be representative of something more general than street side conditions.

The relationships between the minimum separation of sources and monitors, and the maximum concentration impacts of those sources has been derived largely from empirical relationships found in past data, but standard Gaussian diffusion equations have also been used to establish some of the siting specifications. The relationships, empirical or theoretical, have also been used to derive the minimum separations necessary to keep the influence of individual sources below specific levels at neighborhood or regional monitoring sites.

In those instances where a source-oriented monitor is being sited, the same relationships can be applied for virtually the opposite purpose--that is, to identify areas where the impact of a single source will be greatest. In the discussions of source-oriented monitoring presented in this report, two kinds of impact are identified. The first is the short-term effect corresponding to the 24-hour standard, and the second is the long-term, or annual, effect. The reason for distinguishing between the two is that the maximum long-term impacts of elevated sources may be quite different from maximum short-term effects, not only in magnitude, but also in their location. Maximum short-term effects often occur much closer to smokestacks and other elevated sources than do the longer-term effects.

The text of this report provides the details of how the areas of maximum impact can be identified for source oriented monitoring. Step-by-step procedures for the identification of suitable neighborhood, regional, and traffic corridor sites are also given and the reader is encouraged to read the complete report if actually faced with the problem of selecting suitable TSP monitoring sites. The major physical characteristics of the two most important site types are tabulated below. Whenever applicable, we have also included the corresponding site type and nomenclature proposed by Ott (1975).

Neighborhood Monitor

Ott type:	"C" - Residential population exposure station.
Scale of representativeness:	Neighborhood
Sampler location:	2 to 15 m above ground level removed from large obstacles by at least twice the height of the obstacle, 20 m from nearest traffic*, 400 m from nearest major roadway with traffic of 50,000 vehicles per day or more.

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* Ott (1975) specifies a minimum distance of 100 m to nearest street with more than 500 vehicles per day, but this seems unduly stringent.

Other requirements: Reasonably homogeneous land use within 1 or 2 km of the site. Large cities of diverse land use should probably have enough stations of this type to characterize the variety of neighborhoods in the town. The surface in the immediate area should have low ground cover to reduce interference from fugitive dust. Traffic counts on nearby streets and wind measurements would be valuable.

Regional Monitor

Ott type: "E" - Nonurban background stations.

Scale of representativeness: Regional

Sampler location: 2 to 15 m above ground level, removed from large obstacles by at least twice the height of the obstacle. At least 10 km from nearest city, in direction that is least frequently downwind; if more than one such station is planned, see discussion in text for preferred directions; 0.5 km from nearest intercity roadway of 50,000 or more vehicles per day, 4 km from any unpaved public road, and at least 40 or 50 meters from even very lightly traveled paved public roads. Other requirements: An underlying surface as dust free as possible, low ground cover desirable. Low lying areas, subject to cold air drainage and stagnation are to be avoided. Wind measurements at the site would be useful.

Source-Oriented Monitor

Ott Type: "F" - Specialized source survey station. Ott's Type F Station appears directed more toward ground-level sources than is envisioned for a source-oriented TSP monitor.

Scale of representativeness: Generally supposed to represent the neighborhood scale effects of a single source.

Sampler location: 2 to 15 m above ground level, removed from large obstacles by at least twice the obstacle height. Should be placed in area of maximum impact of the source--this will differ for short-term and long-term impacts. Methods of using source characteristics and climatological information to locate areas of maximum impact are discussed in the text. If possible, the site should be away from major roadways or other sources that will obscure the effects of the source of interest.

Other requirements: Much the same as for Regional and Neighborhood Monitors. Wind Measurements at the source would be useful.

The above summaries of physical characteristics mention factors such as nearby traffic, homogeneous land use in the surrounding neighborhood, local ground cover, and areas of maximum source impact. As the text makes clear, these are some of the many considerations that are required to properly locate a monitoring site. You don't just go out and put a high volume sampler 2 m in the air and turn it on. Some places are much better for this than others, and this report describes step-by-step procedures for identifying the better locations for the different types of site. In all cases, the first step of the selection process is to gather demographic, traffic, and land-use data, topographic maps, and climatological information. This information is used to identify generally desirable areas, and to reduce their numbers and their size until a final selection is carefully made. When this has been done, the data should be reasonably representative of the desired conditions.

The original premise that served as a basis for categorizing the sites and defining their physical requirements was that the purposes for data collection could be classified according to appropriate scales of representativeness or relationships to individual sources. In fact, the application of the concept of representativeness to the siting problem has also involved relationships between the monitor and sources so that neighborhood or regional sites are located with the intention that they should represent the composite effects of emissions over areas extending kilometers or tens of kilometers away from the sampler. Essentially, the purpose behind the site classification system presented here is to provide an identifiable constituency of emitters for each monitor. For neighborhood stations we have estimated that sources within about 2 kilometers will provide more than half the measured TSP concentrations about 30 or 40 percent of the time unless there are elevated individual sources that impact on the monitor.

In summary, the guidelines presented here will serve as a good technical basis for selecting sites that can be classified into a limited number of comparable types. The standardization of physical characteristics will ensure that comparison among sites of the same type will not be clouded by anomalies in the data arising from peculiarities in the siting. Furthermore, the guidelines are sufficiently consistent with those already proposed elsewhere that there should be little difficulty in combining the schemes to jointly locate monitors for different types of pollutants.

Use of the classification scheme does more than ensure compatibility of data and allow reasonable comparisons among stations of the same type. It also provides a physical basis for the interpretation and application of those data. This should help to prevent mismatches between what the data actually represent and what they are interpreted to represent. If carefully considered selection of monitoring sites could prevent one instance where a large-scale control plan is designed to cure a small-scale problem, then that alone would probably justify the effort required for proper selection of monitoring sites.

I INTRODUCTION

A. Need for Careful Selection of Monitoring Sites

Air pollution has become a matter of considerable public concern because of its adverse effects on public health and property. Laws have been passed to provide a legal basis for instituting actions to reduce pollution to acceptable levels. In the case of TSP, the primary National Ambient Air Quality Standards (NAAQS) have been set at 260 $\mu g\ m^{-3}$ for a 24 hour average and 75 $\mu g\ m^{-3}$ for the annual average. The corresponding secondary NAAQS are 150 and 60 $\mu g\ m^{-3}$. Monitoring can tell whether acceptable levels are being exceeded and provide the measurements necessary to develop or evaluate those control plans that will be effective.

Obviously, the monitoring data have great importance and their collection deserves considerable attention. The question naturally arises: Are some measurements more suitable for their intended purpose than others? Of course, the answer is "yes"; otherwise, this report would not have been written, its objective being to define the characteristics of the most suitable locations. Some extreme examples of unsuitability are easy to imagine, e.g., a particulate monitor in an open, dusty field providing data from which regional control plans are derived, or the collection of samples for assessing respiratory health effects in an area where the total dust loading is dominated by very large, nonrespirable particles.

The uses of monitoring data are important, and their importance can be belittled by improper siting. The importance of the data requires that equivalent importance be attached to the selection of sites. For this reason, we would expect that those selecting sites should be willing to invest an appropriate amount of time and effort in the task. The procedures recommended here are relatively simple, but they do require acquisition and interpretation of considerable information.

B. The Approach to the Problem

Finding the appropriate siting criteria for monitoring stations starts by finding why the pollutants of interest are monitored. Siting criteria are rules describing the proper physical location of a monitor, and they should be physically related to the reasons for monitoring. The second step toward finding the appropriate siting criteria for different monitoring purposes is the categorization of those purposes according to a physically based classification system. Then it is necessary to identify physical siting criteria corresponding to each set of objectives.

As a prelude to the development of siting criteria, the uses of total suspended particulate (TSP) data were surveyed. Generally, the interpretation given to TSP data assumes that the measurements represent areas and volumes that extend well beyond the limited area and the small volume that is actually sampled. The area presumed to be represented may range from the intermediate in size, like a neighborhood, to a whole region of the country.

The methods for locating stations that have evolved during this study have been based on the premise that the major purposes for establishing a certain monitoring site can be identified and then paired with a scale of representativeness that is most suitable for those purposes. Thus, the site selection process begins by identifying the purpose of the monitoring. This purpose provides a basis for selecting a station type, based on the area that the measurements should represent. Finally, procedures are followed that lead to sites that represent areas of the appropriate size.

Total suspended particulate data have another characteristic that affects the connection between monitoring purpose and site characteristics: particle size. Size is important for three reasons:

(1) Mass concentration varies with size

(2) Particle removal processes depend on size

(3) Health effects, particularly respirability, are influenced by size.

Thus, spatial scale as a basis for classifying monitoring sites is not enough, and the system has to be extended to include consideration of the particle sizes of greatest interest. The incorporation of particle size into the list of factors to consider in the monitoring sites is consistent with the philosophy that the monitoring goals derived from social, scientific, or legal requirements should be translated into a corresponding set of desirable, physically defined goals, which in turn, can be related to actual physical characteristics of an appropriate monitoring site.

II SPECIAL CHARACTERISTICS OF PARTICULATES

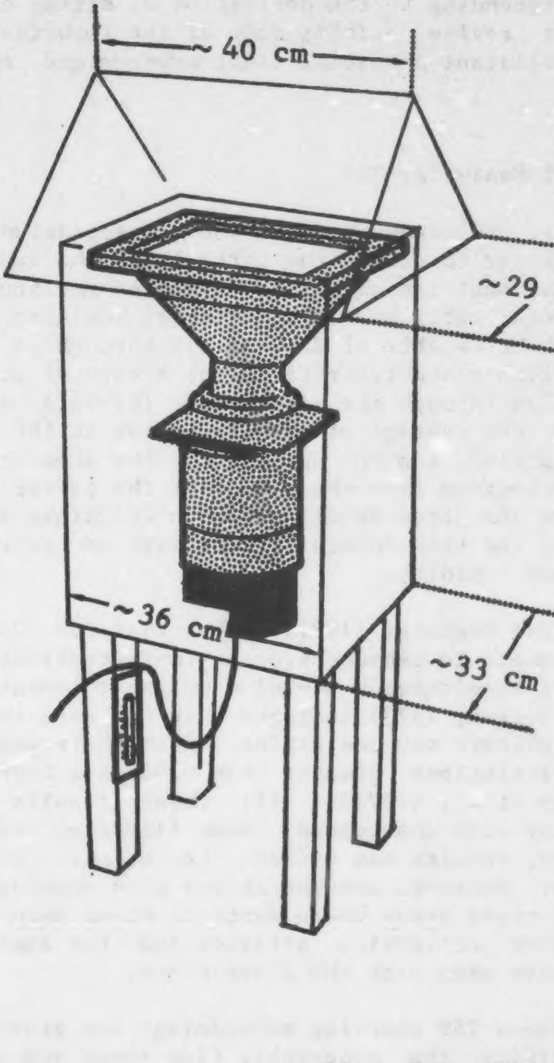
Before proceeding to the derivation of siting criteria, it will be worthwhile to review briefly some of the important characteristics of natural and pollutant aerosols, their sources and methods of measurement.

A. Method of Measuring TSP

Basically, the measurement of TSP concentration entails drawing air through a filter to remove the particles. The sampled air volume must be measured, as must the amount of collected particulate. According to the regulations published in the Federal Register (1971), the approved apparatus must be capable of drawing air through an 8 by 10 inch (20.3 by 25.9 cm) clean glass fiber filter at a rate of at least $1.7\ m^3\ min^{-1}$. Average air flow through the high-volume (Hi-Vol) sampler can be estimated from the average of the flow rates at the beginning and end of the sampling period, and the duration of the sampling. The mass collected is determined from the weight of the filter (to the nearest milligram) before and after sampling. Both weighings are to be made after the filter has had time to equilibrate with an environment of controlled temperature and humidity.

The Federal Register (1971) states that for 24-hour samples, the method is adequate to measure average concentrations as low as $1\ \mu g\ m^{-3}$. Comparisons of simultaneous Hi-Vol sampling (Clements et al., 1972; Lee, Caldwell and Morgan, 1972) indicate that for more than 80 percent of the cases, the duplicate samples differed from their mean by less than ten percent. Correlations greater than 0.99 were found between concurrent samples by Lee et al. (1972). All these results suggest reasonable reproducibility with the method. When filter materials other than glass fiber are used, results may differ. Lee et al. (1972) found a tendency toward higher measured concentrations when membrane filters were used, especially in those areas where particle sizes were smaller, suggesting somewhat higher collection efficiencies for small particles with the membrane filters than with the glass fiber.

The approved TSP sampling methodology (as given in the Federal Register) specifies the acceptable flow rates and sampling materials to provide a degree of standardization. Similarly, the shelter for the sampler is also prescribed. Figure 1 is a schematic representation of the shelter and a properly mounted Hi-Vol sampler. The dimensions shown in the Figure are approximate; there is supposed to be $193.5\ cm^2$ to $580.5\ cm^2$ of clearance between the shelter roof and sampler housing (Federal Register, 1971). With this clearance, sampling of particles as large as 100 µm is supposed to be possible. However, the Lawrence Berkeley Laboratory (LBL, 1975) reports that the passage of large particles into the sampler depends on wind speed as well as size. At low wind speeds, 100 µm particles may be excluded, while at higher wind speeds, particles as large as 200 µm may be sampled.


~ 40 cm
~ 29 cm
~ 36 cm
~ 33 cm

Source: Federal Register, 1971

FIGURE 1 HI-VOLUME SAMPLER AND SHELTER

Whatever its shortcomings, the Hi-Vol sampler in a standard housing is the most widely used instrument for sampling TSP. It is the currently accepted "standard" method (Hoffman et al, 1975), although many other methods exist, based on many principles other than Hi-Vol filtration--e.g., inertial impaction, light scattering, light transmission, centrifugation, ability to serve as droplet nuclei and so forth. This report is directed solely to the siting of the "standard" instrument described in the Federal Register. Many of the same principles can be extended to other methods, should the reader care to do so.

B. Particle Size

As noted, the TSP monitoring method considered here is supposed to be effective over all size ranges up to about 100 µm. The measurements are based on total particle mass. For monitoring purposes of this kind, a single 100-µm-diameter particle is equivalent to 10^6 1-µm-diameter particles, or 10^9 0.1-µm-diameter particles. This emphasis on mass results in some conflicts of purpose that have to be resolved in the development of siting criteria. These will be discussed later.

The size of a particle affects its behavior in a multitude of ways from light scattering to settling velocity. Figure 2 (Lapple, 1961) provides a convenient summary of size-related characteristics of aerosol particles. Among the more important characterisitics is the terminal velocity for gravitational settling in air. Figure 2 shows that submicron particles fall very slowly, less than about 25 cm hr^{-1}. The terminal velocity increases rapidly with size, reaching about 2000 cm hr^{-1} for a 10-µm-diameter particle. Obviously, submicron particles are likely to stay airborne longer and be transported farther than the 10 µm and larger particles, a fact of some importance to the siting process.

The settling velocity of a particle is a reflection of the way in which the particle moves through the air when a force or acceleration is applied. Small particles move very little relative to the air; large particles move a lot. When moving air encounters an obstacle, its flow is changed and accelerated around the object. Small particles will tend to follow the air and bypass the obstacle, but larger particles are much more likely to continue along their original path and may impact and be removed from the air stream. The theory of impaction of particles is beyond the scope of this work (see for example, Ranz and Wong, 1952); it should suffice to note that larger particles are more subject to removal by impaction on leaves, twigs, buildings, or any other obstacle to air flow. Again, the importance of this phenomenon to aerosol sampling should be apparent.

If particles are subject to removal by accelerations around buildings or vegetation, it seems likely that they might also be subject to impaction and removal during their movement through the many passages to the respiratory system, and they are. Figure 3 shows the fraction of

CHARACTERISTICS OF PARTICLES AND PARTICLE DISPERSOIDS

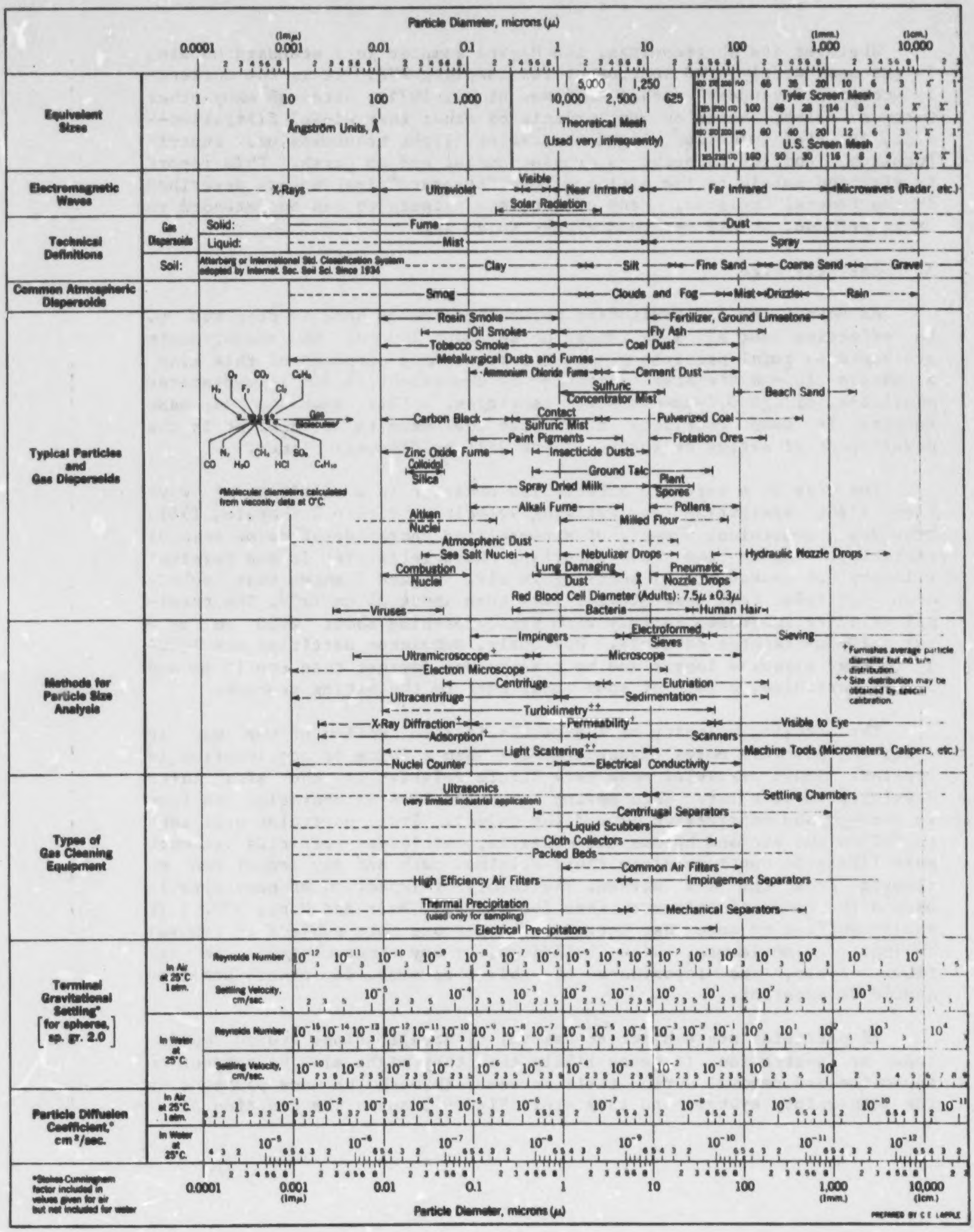


FIGURE 2 CHARACTERISTICS OF PARTICLES AND PARTICLE DISPERSIONS

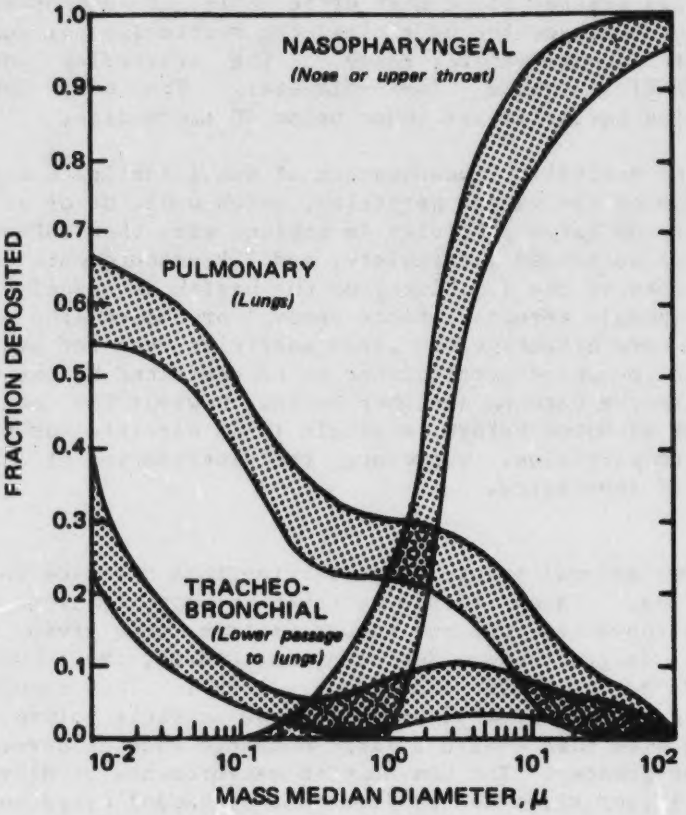
the total breathed particles retained in different parts of the respiratory system as a function of the mass median particle size (Task Group on Lung Dynamics, 1966). The extremes represent different standard geometric deviations of the inhaled aerosol particles. Deposition in the lungs is a much greater hazard with particles of submicron diameter than with the larger particles that tend to be trapped in the nasal and upper respiratory passages.

The role of particles in visibility reduction is another of the reasons often given for TSP monitoring and here, too, particle size is an important factor. Reduction in atmospheric visibility is caused by light scattering in the aerosol. According to Foxvog (1975), single "absorbing particles scatter light most efficiently for diameters near 0.2 µm, whereas for nonabsorbing particles, the scattering per unit mass peaks in the 0.4 to 1.0-µm-diameter range." The scattering per unit mass falls rapidly toward 10 µm-diameter. The most important visibility- reducing particles are those below 10 µm in size.

The health and visibility consequences of small particles are more severe than those of the larger particles, which would be of no importance if there were no large particles in ambient air; then TSP would be equivalent to small suspended particulate, and TSP measurements would be reasonable indicators of the visibility or the health degradation potential of the atmospheric aerosol. Since removal processes like settling and impaction are more effective for large particles than for small, we might expect the measured particulates to be dominated by the smaller particles. This is the case on a number basis. However TSP monitoring measures mass and as noted before, a single 10-µm particle has the mass of a million 0.1-µm particles. Therefore, the distribution of mass with particle size is of importance.

Figure 4 shows several volume size distributions observed in various U.S. locations. These should be taken as approximations because several have been converted from the number distributions given in the original sources (e.g., Junge, Robinson, and Ludwig, 1969; Ludwig and Robinson, 1971; Peterson, Paulus and Foley, 1969). The results are quite interesting in that several examples show particle volume distribution increasing with size toward a large particle mode at several microns diameter or greater. The Los Angeles measurements of Hidy et al. (1975) extend to larger sizes and confirm that a bimodal distribution is common. Figure 5 shows the idealized urban size distribution hypothesized by Hidy et al. (1975). According to that reference, the mode at smaller sizes represents the anthropogenic contribution to the urban aerosol while the larger material with a volume mode at about 10 µm diameter is of natural or "quasi-natural" origin. The chemical elements that are usually found in the larger particulates, the "blowing dust," although referred to as natural, is as likely to be from road dust, construction activity, and so forth.

Flocchini et al. (1976) have found similar size separation of elements in their California samples. Silicon compounds, prime dust components, are almost all found in particles larger than 3.6 μm; about 80 percent of such materials were between 3.6 and 20-μm diameter. On the other hand, about 80 percent of the lead compounds were found in the size range 0.11 μm to 0.65 μm, consistent with the findings of others (e.g., Lee, Patterson and Wagman, 1968; Robinson and Ludwig, 1967) in other parts of the country. Lead has often been assumed to be associated with auto exhaust.



Source: Task Group on Lung Dynamics, 1966

FIGURE 3 FRACTION OF PARTICLES DEPOSITED IN THE THREE RESPIRATORY TRACT COMPARTMENTS AS A FUNCTION OF PARTICLE DIAMETER

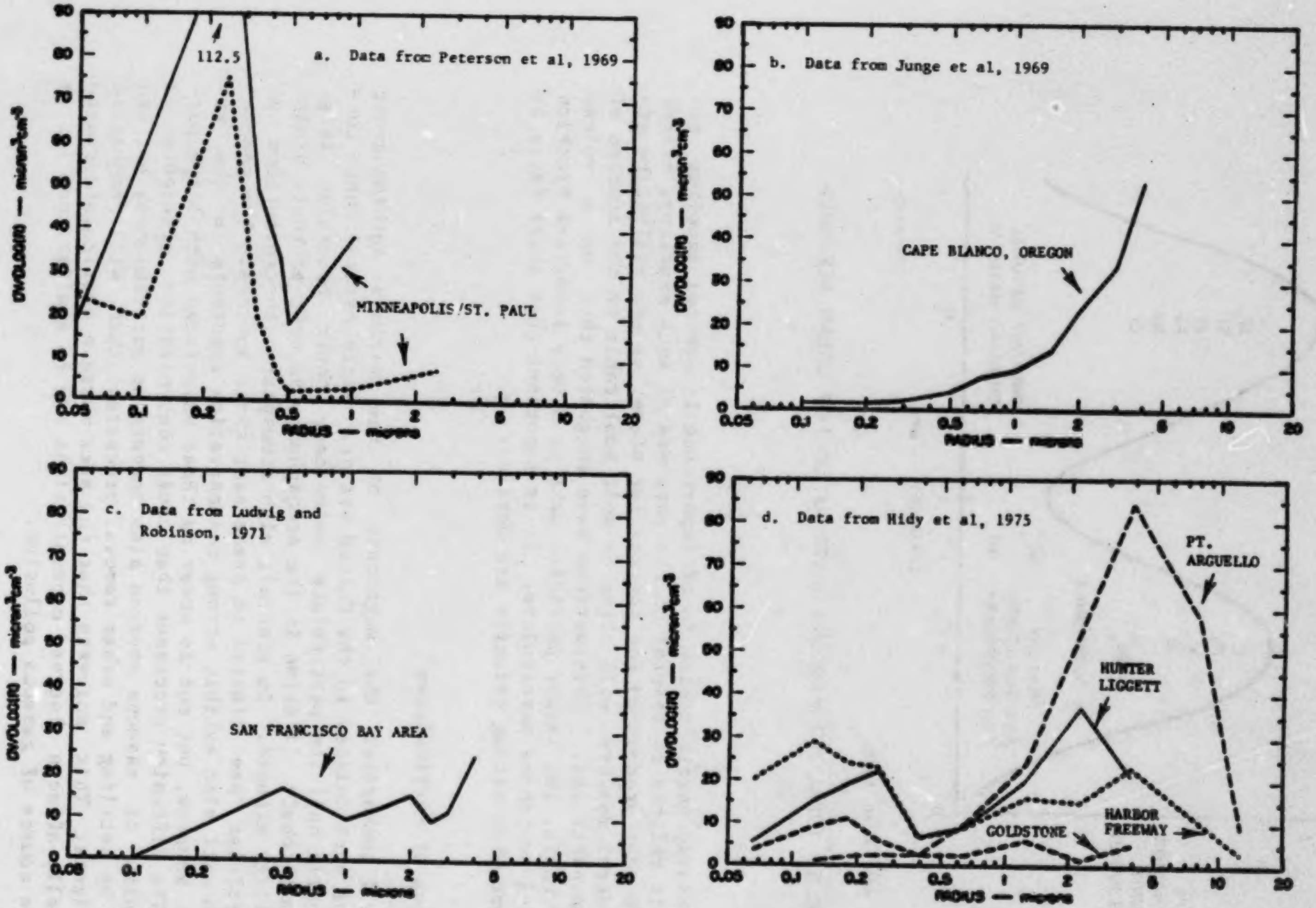
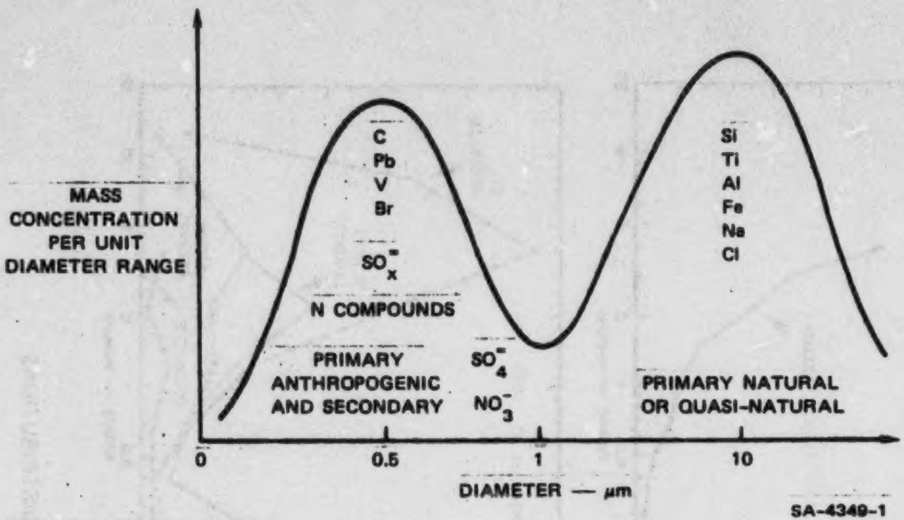


FIGURE 4 SOME OBSERVED PARTICLE-VOLUME SIZE DISTRIBUTIONS



SOURCE: Hidy, et al., 1975.

FIGURE 5 IDEALIZED MASS/SIZE DISTRIBUTION FOR URBAN AEROSOLS

In summary, particle size is of importance in aerosol sampling because it is related to several of the purposes of such sampling. Health effects are most pronounced for the smaller sizes, as are visibility effects. Control measures will often be most applicable to the sources of the smaller particles. Observations have suggested that on a volume (or mass) basis, the larger particles make up a very important fraction of the total suspended particulate. It is important that these facts be acknowledged when siting criteria are derived.

C. Sources of Particulates

Table 1 summarizes the magnitude of the various anthropogenic sources of particulates in the United States. While natural dusts constitute nearly half the particulate emissions, their generally large sizes limit their lifetime in the atmosphere, as well as their health and visibility effects. In general, high atmospheric concentrations of large particles are limited to areas near their sources. The gaseous pollutants will also exhibit strong concentration gradients in the vicinity of sources, but not as great as those associated with large particles. The diffusion processes that cause concentration gradients in the vicinity of gaseous sources also operate on particulates, but are augmented by settling and other removal processes that will emphasize the gradients. This suggests that the area where a particulate source substantially affects observed concentrations may be smaller than for a comparable source of gaseous pollution.

Table 1

NATIONWIDE EMISSIONS
ESTIMATES FOR 1974

SOURCE CATEGORY	EMISSIONS 10^6 t/yr	PERCENT OF TOTAL
Transportation		
Highway	0.9	4
Non-highway	0.4	2
Stationary Fuel Combustion		
Electric Utilities	3.4	17
Other	3.6	18
Industrial Processes		
Chemical	0.2	1
Petroleum Refining	0.1	<1
Metals	1.5	7
Mineral products	6.3	31
Other	2.5	12
Solid Waste	0.6	3
Miscellaneous		
Forest wildfires	0.5	2
Forest managed burning	0.1	<1
Coal refuse burning	0.1	<1
Structural fires	< 0.1	0
Other	0.1	<1
Total	20.3	100

Source: EPA-450/1-76-002, Nov 1976, National Air Quality and Emissions Trends Report, 1975.

One final comment is in order regarding the interpretation of the figures given in Table 1. The table says nothing about reentrainment of large particles after they have been removed. Soil erosion may repeatedly involve the same particles. In the extreme, this is "saltation," where large particles are eroded by the wind but not truly suspended in air so that their progress is made through a series of hops and jumps over the surface. It is not always clear how the evaluation of emissions should treat reentrainment. Cowherd et al. (1974) have adopted a minimum significant travel distance of about 6 m in their evaluations of emissions from fugitive dust sources. According to their calculations this criterion eliminates most of those particles larger than 100 μm at wind speeds less than about 5m s^{-1}--consistent with the sampling size limitations of the Hi-Vol sampler shelter. Effectively, this constitutes a definition of particulate emissions from ground-level sources--they are those which become sufficiently well suspended in the air to be transported at least 6 m. If they travel beyond that distance, settle to the ground, and later become resuspended in the wind, then presumably that reintroduction constitutes a new emission to be added once again to the year's total emissions. Obviously, considerable potential exists for ambiguity in the interpretation of the annual emissions given in Table 1. Fortunately, this ambiguity is generally limited to the large particulates, especially those in the category of natural and fugitive dusts. As has been discussed earlier, these are usually the materials least important to health or to visibility reduction.

III DECIDING THE TYPE OF TSP MEASUREMENTS THAT ARE TO BE MADE

A. Uses of Total Suspended Particulate Measurements

The objective of this section is to present a unified theme for classifying monitoring stations. Our approach to this objective has been to start with a simple list of the uses of ambient TSP concentration data, which was compiled by searching the literature for reports and papers that made use of such data (see Appendix B). The ways in which the data had been used were assembled and listed without regard to their relative importance or to the possible overlapping of objectives. In the list that follows, we have tried to group the purposes into general categories:

1. Evaluate Air Quality and Air Quality Trends
    - Determine adherence to air quality standards:
        - Federal primary
        - Federal secondary
        - State or local.

2. Development and Evaluation of Controls
    - Evaluate results of control measures
        - "Hot spots"
        - Overall urban conditions
        - State, regional, or nationwide conditions.
    - Determine long-term trends in TSP concentrations:
        - In an urban area
        - Provide information for city and regional planners and decision-makers.

3. Public Health
    - Evaluate the effects of human exposure to ambient aerosols.
    - Determine the relationship of ambient outdoor TSP levels to those inside buildings.
    - Evaluate TSP effects on animals and plants.

4. Research

- Determine effects on the environment, e.g.,
  - Visibility
  - Condensation processes
  - Attenuation of solar radiation.
- Provide information for better understanding of the processes affecting TSP concentrations:
  - Removal mechanisms
  - Transport processes
  - Objective modeling: development, evaluation, and refinement.
- Provide information for evaluating fugitive dust sources

5. Miscellaneous

- Test monitoring equipment and methods.
- Assess representativeness of existing or proposed monitoring sites.

The list of purposes given above is quite diverse, and it may not be immediately obvious that a coherent, physically based classification system is possible. Ludwig and Kealoha (1975) used some of the ideas of Ott (1975) to classify a similar list of carbon monoxide monitoring objectives according to the spatial scales of representativeness that were most appropriate to each of the monitoring objectives. Such a scheme satisfies the need for a physical basis to the classification system; the physical basis is important because the classification system has to be related to a set of appropriate physical site characteristics.

Any useful measurement of TSP concentration is supposed to represent some volume and some period of time. The measurements always entail time averaging because the sample is collected over a finite period; at the same time, some spatial averaging occurs because of the finite volume of air that is collected. In general, this volume does not correspond to the objectives of the monitoring. The objectives may require representation of volumes considerably different from those from which the samples are drawn. Site selection, when viewed from this perspective, consists of selecting a location or locations where concentrations in the volume sampled can be related to concentrations representative of the volume that is required to meet objectives.

B. Classification of Monitoring Purposes

1. Appropriate Spatial Scale of Representativeness

The categories of spatial representativeness used for classifying the various objectives are listed below. They are presented in order, from the smallest scale to the largest scale of measurement. Their relative importance will be discussed later.

a. Microscale

This refers to volumes with dimensions of meters to a few tens of meters, smaller than downtown street canyons or below-grade highways. Those special studies attempting to determine TSP distributions within parking lots, within street canyons, over unpaved highways, or around fugitive dust sources will require microscale measurements. The development and testing of models to describe the processes that produce the observed details of such concentration distributions would also require data of this scale.

b. Middle Scale

Much of the short term (up to a few hours) public exposure to particulates is on this scale. People moving through downtown areas, or living near major roadways, encounter particulates that would be adequately characterized by observations of this spatial scale. Thus, measurements of this type would be very appropriate to the evaluation of some of the possible short term public health effects of particulate pollution, but the air quality standards are based on 24- hour and annual averages.

This class also includes the characteristic concentrations for other areas with dimensions of a few hundred meters, such as the parking lot and feeder streets associated with indirect sources--that is, complexes that do not produce pollutants themselves but which attract significant numbers of pollutant producers, such as autos. Shopping centers, stadiums, and office buildings are examples of indirect sources. In the case of TSP, unpaved or seldom-swept parking lots associated with such attractions could be an important source in addition to the vehicular emissions themselves.

This category also may be applicable to streets that are several kilometers long, if sources and land use are reasonably homogeneous along the street, but inhomogeneous in other directions, such as is the case with strip development, freeway corridors, or downtown street canyons. We have included in this category special measurements to characterize the TSP concentrations from emissions and road dust along such traffic corridors. A site for monitoring the conditions in a single street canyon, or a block of strip development, will be representative on a scale of tens of meters by hundreds of meters. If we try to characterize street-side conditions throughout the downtown area, or along an extended stretch of roadway, then the characteristic dimensions may be tens of meters by kilometers.

c. Neighborhood

Measurements in this category would represent conditions throughout some reasonably homogeneous urban subregion, with dimensions of a few kilometers and generally more regularly shaped than the middle scale. Homogeneity refers to TSP concentration, but it probably also applies to land use and land surface characteristics. In some cases, a site carefully chosen to provide neighborhood-scale data might represent not only the immediate neighborhood but also neighborhoods of the same type in other parts of the city. Stations of these kinds provide the best information about health effects and compliance with regulations because they represent conditions in areas where people commonly live and work for periods comparable to those specified by the NAAQS. In the sense used here, this category includes industrial and commercial neighborhoods, as well as residential.

Neighborhood-scale data could provide valuable information for developing, testing, and revising concepts and models that describe the larger-scale concentration patterns, especially those models relying on spatially smoothed emission fields for inputs. The neighborhood scale measurement could also be used for interneighborhood comparisons within, or between, cities. This is the most likely scale of measurement to meet the needs of planners.

d. Urban

This class of measurement would be made to typify the particulate concentration over an entire metropolitan area. Such measurements would be useful for assessing trends in citywide air quality and, hence, the effectiveness of larger-scale air pollution control strategies. Measurements that represent a citywide area would serves as a valid basis for comparisons among different cities.

e. Regional

These measurements would characterize conditions over areas with dimensions of as much as hundreds of kilometers. As noted earlier, representative conditions in an area imply some degree of homogeneity in the area. For this reason, the class of regional measurements would be most applicable to sparsely populated areas with reasonably uniform ground cover, at least as it relates to surface dust entrainment. Data characteristic of this scale would provide information about larger-scale processes of particulate emissions, losses, and transport.

f. National

Measurements that defined concentrations on this scale would characterize the TSP level of the nation as a whole and would provide trend data to allow assessment of national policies. Such data might also be useful for studying international and global transport processes.

g. Global

Such measurements would provide information useful to the identification of worldwide trends in aerosol concentrations.

The above list categorizes measurements according to the spatial scale to be represented. Virtually all uses of TSP measurements entail the characterization of concentration on one or more of these scales. Some scales would be difficult, and perhaps impossible, to represent with a measurement at a single site. Thus, there need not necessarily be a site category that corresponds to each of the above scales of measurement; some scales will have to be represented as composites of measurements characterizing smaller areas.

2. Most Important Particle Sizes

It should be clear from discussions in Section II that different monitoring purposes may be satisfied by measurements of concentrations of particulates in different size ranges. Unfortunately, the methodology most commonly used for TSP measurements does not discriminate among different sizes--at least for those particles smaller than about 100-μm diameter. Nevertheless, the requirement for some size discrimination persists and must be satisfied to whatever extent is possible through proper siting.

Recognizing that it would be unrealistic to expect to achieve fine resolution of particle size through siting criteria alone, we have chosen to consider only two categories, "small", or "respirable" versus "total." Nominally, "total" includes all those particles which the standard Hi-Vol system normally collects. The most obvious application of this category is to meet the legal requirements associated with air quality standards. Another possible application might be to determine potential effects of dust loadings on equipment or materials.

Above 5-μm diameter, most of the inhaled particles are deposited in the nose and throat (see Figure 3). Such particles also have appreciable settling velocities and are subject to relatively efficient removal by inertial processes, as noted before in this report. Finally, as Figure 5 shows, the bulk of the material from natural and "quasi-natural" dust-raising processes falls in this size range (Hidy et al., 1975). Therefore, it seems appropriate to try to consider monitoring purposes according to whether they are best served by measurements nominally limited to the "small particles"--smaller than 5 μm--or by measurements that cover the total size range--at least up to 100 μm.

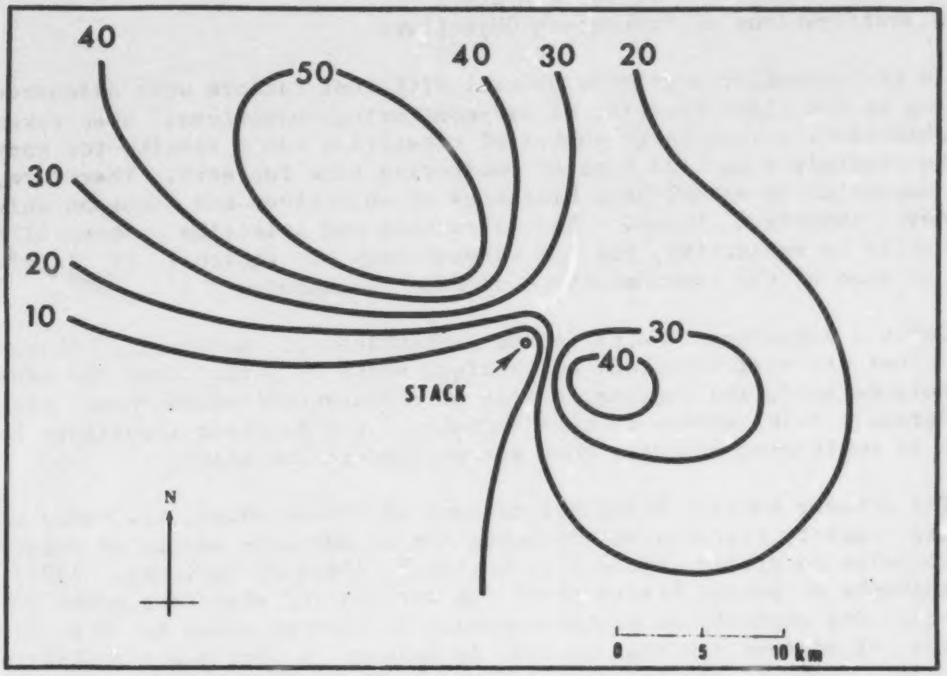
Many of the purposes for monitoring aerosol concentrations would be better served by measurements of the small, respirable fraction, rather than of the total mass per unit volume. The most obvious of these are the measurements made to assess health effects, but others also fall in this category. For instance, the environmental effects of the small particles are apt to be more profound than those of the large particles; aerosol effects on visibility, attenuation of solar radiation and cloud condensation processes are all more pronounced, mass for mass, for particles in the smaller size range than for the larger particles. Finally, if the hypothesis of Hidy et al. (1975) is true, and most of the primary and secondary aerosols from anthropogenic sources are in the smaller size range, then measurements made to evaluate the effectiveness of controls on anthropogenic emissions would be best limited to the smaller sizes.

Unless considerable care is taken during the selection of sites for TSP monitoring, the data may be overly influenced by the large particles that are not the major threats to public health and environmental quality. Furthermore, data that are overly influenced by the large particles may not be as useful for the formulation of control strategies as are data that are more representative of the concentrations of small particles. While it may not always be possible to overcome the large particle effects by siting, recognition of the problem should improve data interpretation and reduce the impact of the problem.

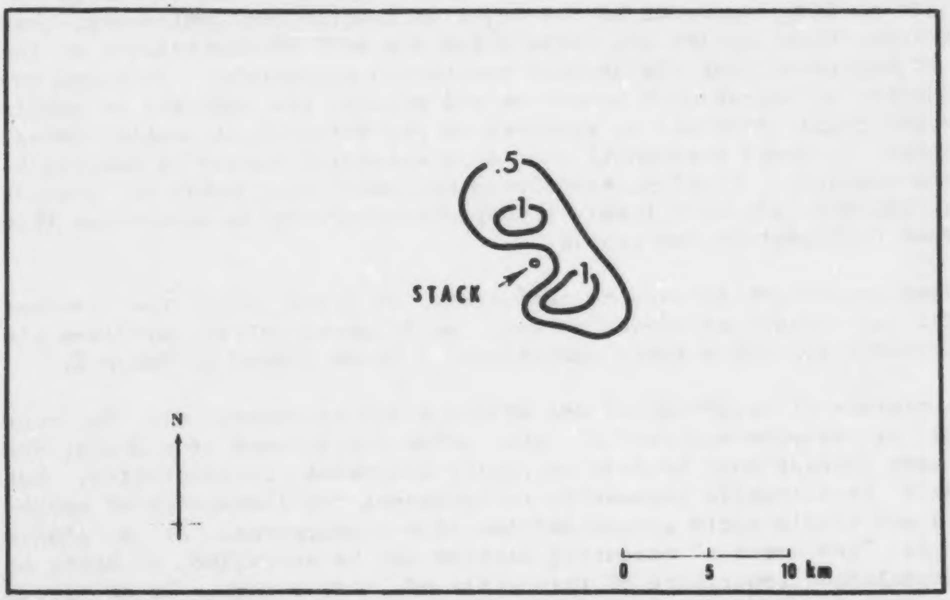
3. Source-Oriented Monitoring

Sometimes, TSP is monitored to assess the effects of a large source on its surroundings. If this source is at ground level, then it may be possible to define the objective in terms of scale of representativeness. For instance, effects from large traffic sources will be adequately assessed by measurements that describe the middle-scale traffic corridor conditions.

Large, elevated particulate sources will usually have their greatest impact at distances well removed from the source. Furthermore, there will be differences between the areas of maximum long-term average impact and those where shorter-term effects (in this case, 24-hour average) are felt. Figure 6 shows the impacts of a hypothetical 160 m stack calculated with the model described in Appendix A. The climatological inputs used were those from Tucson, Arizona. The units are relative, since the numerical results will depend on the source strength. For purposes of monitoring, the important features to note in Figure 6 are the differences between the location and relatively large extent of the area of maximum long-term average concentration and the location and comparatively small size of the areas where very high, 1-hour concentrations are most frequently observed. When locating a TSP monitoring station to evaluate the impacts of a large, elevated point source, it is important to determine which type of impact is more important, long-term averages or most frequent high concentrations of short duration. The usual averaging period for TSP sampling is 24 hours. The difference between the location of the maximum 24-hour average and that of the greatest annual average are not apt to be so pronounced as the differences in Figure 6, between the locations of the maximum annual average and most frequent high 1-hr average, but must still be considered in the siting of monitors.


40
50
40
30
20
30
20
10
30
40
STACK
N
0
5
10 km

(a) LONG TERM AVERAGE IN ARBITRARY UNITS


.5
1
STACK
1
N
0
5
10 km

(b) PERCENTAGE FREQUENCY OF CONCENTRATIONS EXCEEDING 1300 ARBITRARY UNITS

FIGURE 6 CALCULATED IMPACTS OF A HYPOTHETICAL 160 m STACK LOCATED IN THE SOUTHWESTERN UNITED STATES

C. Relative Importance of the Different Classifications of Monitoring Objectives

In the preceding sections, several different factors were discussed relating to the classification of TSP-monitoring objectives. When taken in combination, a very large number of categories could result--too many to make feasible a special type of monitoring site for each. Therefore, it is essential to establish a hierarchy of objectives and focus on only the most important types. Such a ranking and selection process will necessarily be subjective, but can nevertheless be rational if it is based on some of the considerations already discussed.

Table 2 summarizes the different categories of monitoring objectives that are most important and assigns ranks to them. Only the middle, neighborhood, and regional scales of representativeness have been considered. This arises in part because of the dominant importance we attach to monitoring purposes that are related to the NAAQS.

The primary ambient NAAQS are defined as "those which, ... based on the air quality criteria and allowing for an adequate margin of safety are requisite to protect the public health." (Federal Register, 1971). The emphasis on public health gives the air quality standards great importance. The emphasis on public exposure is further shown by the definition of ambient air that is used in connection with the air quality standards: "Ambient air is that portion of the atmosphere, external to buildings, to which the general public has access." If we accept ambient air quality standards as the major motivation for monitoring, then the most important scales are those which are most characteristic of the kinds of exposures that the general population encounters. Although the air quality standards must be met on all scales, the emphasis on public health and public exposure is apparent in the definitions quoted above, and hence it seems reasonable that site selection should be subject to the same emphasis. Finally, experience has shown that areas of greater public exposure are more likely to experience standards violations than are areas that contain few people.

Most people are exposed to pollutants, at least over the 24-hour periods, on neighborhood-scale and, to a lesser extent, middle-scale This accounts for the evident importance of these scales in Table 2.

A mixture of neighborhood and middle scale exposures can be considered as respresentative of the urban environment as a whole, and hence some attempt must be made to typify urbanwide concentration, but it would be virtually impossible to represent the hodgepodge of neighborhood and middle-scale concentrations with measurements at a single site; no "urban-scale" measuring station can be described, in spite of the acknowledged importance of this scale of measurement. Urban areas must be characterized by networks of stations covering a range of conditions within the area. For this reason, the urban scale has not been included in Table 2.

A large segment of the population dwells in areas that could be characterized by regionally representative sites, and so this scale must be included in the table. However, it is probably not as important as the smaller scales because "regional" areas will be more rural and generally have lower concentrations of people and pollutants, thereby being less critical for consideration.

Microscale measurements for health-related purposes are not very appropriate, because very few people remain within a rather small area for the 24-hour period of the standard. The numbers of people affected by TSP exposures on the microscale are very small compared to other categories. There is another reason for omitting objectives met by microscale observations from consideration in Table 2. Our survey of the literature suggests that those making microscale measurements, and even many middle scale measurements, have specialized requirements that would be difficult to generalize. The users are most often research oriented and develop their own criteria, carefully matched to their own specific aims. The usual requirements associated with microscale measurements tend to be beyond what we consider to be the primary scope of this report--to provide guidelines for the siting of more routine monitoring stations.

Table 2

CATEGORIES OF TSP MONITORING OBJECTIVES
RANKED ACCORDING TO IMPORTANCE

Class of Objective	Important Scales To be Represented	Ranking
Determination of the impact of specific sources or categories of sources	Middle or Small area	3
	Neighborhood	2
Determination of prevailing ambient conditions	Neighborhood	1
	Regional	6
Development and evaluation of control strategies	Middle	5
	Neighborhood	4

National- and global-scale measurements have not been incorporated into Table 2 because they are representative of such large areas that they do not relate to the exposure of the general public. Furthermore, they are largely redundant. To some extent this is also true of the urban scale. If the middle- and neighborhood-scale measurements have adequately characterized the city's streets, shopping centers and neighborhoods, then all the necessary information is available for characterizing the city as a whole. Similarly, if the cities and regions are adequately described, their descriptions can be synthesized into a national description, and on to the global scale.

Basically, the ranking shown in Table 2 arose because we attached the greatest importance to the acquisition of data for defining health hazards and for determining adherence to air quality standards. Thus, only the middle, neighborhood, and regional scales of representativeness are considered. Of these three, the objectives related to the determination of prevailing ambient neighbornood conditions are judged more important than those related to the assessment of the impact of more specific sources, because the problems associated with prevailing, ambient conditions are, inherently, more widespread than those associated with the local impact of an individual source. The middle-scale monitoring of particulates is most likely to be associated with specific sources, such as roads, dusty storage areas, and parking lots. Finally, the measurement of neighborhood conditions was given precedence over regional (generally nonurban) conditions, because as noted before, the numbers of people exposed to neighborhood conditions are likely to be higher, as are the concentrations of particulates.

D. Relating TSP Monitoring Purpose to the Appropriate Scale of Measurement

Table 3 summarizes some of the more important applications of the various kinds of monitoring that have been discussed to this point. The purposes are not necessarily listed in order of importance. The X's indicate important general applications; those in parentheses, less general applications. The table is intended to serve as a guide to the selection of site types that are appropriate to the listed monitoring purposes. The principles enunciated in preceding sections should help the reader pick site types appropriate to purposes that are not listed specifically in the table. Procedures are given in the next section for locating the various types of site. Certain features in Table 3 reflect the rankings given in Table 2.

The entries for the neighborhood and regional scales indicate where the smaller size particles are of greatest importance and where particular care should be taken to avoid biasing the measurements with larger particles. In general, middle-scale sites cannot be oriented specifically toward smaller particles. It will not be possible, within the dimensions of the middle scale, to be sufficiently removed from sources so that larger particles can be removed by natural processes. There are only a few instances where total particulate monitoring is useful for typifying neighborhood or regional TSP concentrations, because the irregularities in the distribution of the larger particles and their lesser impacts on health and the environment make emphasis on the smaller particles more reasonable. The reasons behind the entries in Table 3 are discussed individually below.

1. Determine Compliance with Air Quality Standards

The air quality standards stress public exposure over 24-hour or annual periods and health effects, so the most important locations for measurements related to air quality standards will be in areas that combine high concentration with high public exposure. The most likely locations for such a combination are the neighborhoods where people spend great periods of time. Thus, high density residential neighborhoods are likely candidates for stations devoted to this purpose. Industrial neighborhoods are also prime candidates for monitoring because of the many dust sources often present in such areas. Similarly, the possibility that large elevated sources may be causing violations of standards is likely to provide impetus for source-oriented monitoring. Many people spend at least some of their time in the downtown street canyons or near roadways, so conditions in such areas must also be considered. Wherever possible, the emphasis will be on the smaller particles, but the parenthesized X's in Table 3 suggest the possibility that the legal requirement for total particulate monitoring may sometimes override the rational underpinnings of the established air quality standards.

2. Provide Information for the Preparation of Environmental Impact Statements

Very often, projects for which impact statements are required will affect air quality on the middle scale. If the area in which the project is to be located is reasonably homogeneous, then neighborhood-scale measurements can be used to characterize conditions prevailing before the project is begun. Sometimes it will be necessary to make special middle-scale measurements for the purpose. For example, if the project is a highway widening, measurements may be required in the area where the widening is planned. Of course, the implementation of plans that involve stack emissions should probably be prefaced by neighborhood scale measurements in the areas where the greatest impacts are expected, and perhaps special source-oriented measurements in the vicinity of any similar sources that might already exist in the region. All these measurements would usually be made to provide estimates of current conditions against which calculations, and subsequent observations, of post-project conditions could be compared.

3. Determine Impact of Specific Sources

Except for elevated emissions, the impacts of a source diminish at greater distances from the source. Thus, for roadway emissions, or fugitive dust emissions, it is most appropriate to select a monitoring site that will characterize middle-scale conditions in the immediate vicinity of the source. Hence, the different kinds of middle-scale monitor are emphasized for this purpose. Of course, the effects of an elevated source are best defined by a source-oriented monitor.

Table 3

IMPORTANT APPLICATIONS OF DIFFERENT TYPES OF TSP-MONITORING SITE

Monitoring Purpose	Middle Scale		Neighborhood		Regional		Source Oriented
	Special Near Roadway Sites	Small Area	Small Particle	Total Particle	Small Particle	Total Particle	
1. Determine compliance with air quality standards	(X)$^+$	(X)	X*	(X)	X	(X)	X
2. Provide information for preparation of environmental impact statements	(X)	(X)	X				X
3. Determine impact of specific sources:							
Roadways	X						
Ground level area sources		X					
Elevated sources							X
4. Determine effects on the environment:							
Visibility			X		X		
Attenuation of solar radiation			X		X		
Condensation processes			X		X		

Table 3 (concluded)

Monitoring Purpose	Middle Scale		Neighborhood		Regional		Source Oriented
	Special Near Roadway Sites	Small Area	Small Particle	Total Particle	Small Particle	Total Particle	
5. Provide information for better understanding of processes affecting TSP concentrations	X	X	X		X		X
6. Evaluate results of control measures							
"Hot spots"	X	X					X
Urban conditions			X				
Larger scale					X		
7. Determine long-term trends in TSP concentrations:							
Urban			X				
Rural					X	(X)	
8. Evaluate effects on humans	(X)		X				
9. Evaluate effects on animals and plants			X	X	X	X	X
10. Assess representativeness of existing sites			X		X		

X* = general applications
(X)+ = more specialized applications

4. Determine Effects on the Environment

Most environmental effects, especially those noted in Table 3, occur on a fairly large scale and, therefore, neighborhood and regional monitoring are most important. For instance, visibility reduction is a cumulative effect, taking place over distances of several kilometers; the major atmospheric effects that arise from solar attentuation or cloud formation processes also extend over distances of kilometers and more. The emphasis on smaller particles has been discussed already--all the effects noted are much more pronounced with numerous small particles than with the same mass of large particles.

5. Provide Information for Better Understanding of the Processes Affecting TSP Concentration

All categories of monitoring are likely to be useful for defining processes affecting TSP concentration. Total particulate monitoring, at all scales, can be useful to the understanding of the effectiveness of processes that tend to remove the larger particles preferentially. Such monitoring is also essential to the understanding of processes that introduce large particles into the atmosphere and govern their spatial distribution near streets and small area sources.

In the case of source oriented monitoring, interest in both the total size spectrum and the smaller material will arise when one tries to understand the differences in behavior, and in resultant ground level concentration patterns, between the large, rapidly settling material and the smaller sizes with negligible settling.

When the interest is in longer-range transport processes, the emphasis will be on the smaller particle sizes and the larger scales of representativeness because only the smaller particles are subject to such transport, and turbulent mixing over long distances will obscure the smaller-scale features.

6. Evaluate Results of Control Measures

Control measures range from local, small-scale actions, such as street sweeping, to citywide measures, such as restrictions on types of fuel to be used. For specific, smaller-scale control measures, middle-scale monitoring is most appropriate. The type of middle-scale monitoring to be done will be governed by the control measure being evaluated. Controls on a specific, elevated source will require source oriented monitoring for evaluation, but the monitoring need not necessarily be conducted over long periods; the effectiveness of the controls can be established with a limited number of measurements. For evaluating citywide control measures, larger scales of representativeness and longer monitoring periods will be required.

7. Determine Long-term Trends in TSP Concentration

Middle-scale measurements will not be as useful for this purpose as neighborhood-scale measurements, because the middle scale sites are highly influenced by large, and often erratic, fluctuations in emissions over a relatively small area. When the emissions influencing a location are averaged over a larger area, then the fluctuations in concentration will more realistically reflect meteorological factors and changes in emissions that are more widespread than those that affect the middle scale. Therefore, the neighborhood- and regional-scale measurements of smaller particles are likely to be most suitable for evaluating long-term trends in TSP concentration. There may be instances in rural areas, when it is appropriate to consider the total particulate loading because of its relationship to the nature of the ground surface and erosion processes.

8. Evaluate Effects on Humans

If one were specially designing a monitoring program to evaluate effects on humans, one probably would not use conventional TSP monitoring methods, but would use techniques that would provide separate information about the respirable and nonrespirable fractions and about specific chemical constituents. However, if forced to use existing data, the best choices would be those data collected at sites where people were most frequently found and where the larger particles were not likely to dominate the samples.

9. Evaluate Effects on Animals and Plants

The same arguments apply to the study of particulate effects on plants and animals as to the effects on humans, but in the case of plants respirability is not a factor. The larger particles are more subject to deposition on the foliage than are the smaller materials.

10. Assess Representativeness of Existing Sites

Table 3 indicates that only neighborhood- and regional-scale sites that emphasize the smaller particles are suitable for assessing the representativeness of similar, existing sites. This reflects the difficulty in defining and measuring representativness for a parameter with great, small-scale spatial variability. In such cases, techniques other than conventional TSP monitoring--such as mobile nephelometry (see, e.g., Charlson et al., 1969), or widespread use of small membrane filters, or lidar (laser radar) probing--might provide the necessary information.

Table 3, relating general monitoring purposes to the various scales and particle sizes to be characterized, supports the rankings given earlier in Table 2. Most purposes are best served by neighborhood measurements, especially those emphasizing the small particles. The following sections, therefore, emphasize the selection of sites that will represent neighborhood conditions, especially the concentrations of the smaller particulates. Regional scale and source oriented monitoring also warrant considerable attention. The monitoring of middle-scale conditions must also be discussed, although this scale is not as consistent with the averaging periods specified for assessing compliance with the NAAQS.

IV SELECTING THE STATION LOCATION

The purpose of this section is to provide step-by-step procedures for locating monitoring stations that will serve the most important measurement purposes. For the more general purposes, this means identifying a site that is characteristic of the appropriate spatial scale and which, for neighborhood- or regional-scale measurements, does not overemphasize the larger particles. For source-specific monitoring, it requires the identification of a location where the source is likely to have its greatest impact. The major steps of the site-selection process are presented in flowcharts, with accompanying discussions. The reasoning behind the recommendations made in this section is deferred to Section V so that the procedures themselves can be presented more concisely.

A. Regional Stations

Figure 7 shows schematically the site-selection process for a regional-type TSP monitor. The form of the flow chart reflects the differences between selecting a single site and a set of sites. Differences between procedures for selecting sites to define background TSP concentrations for a specific city, and those for selecting regional stations for more general purposes are also evident in the chart.

The site selection process begins with acquisition of the necessary background material. This material is to be used as a basis for the judgmental decisions that are required during the selection process. Three basic kinds of information are required: geographical, emissions and climatological. The geographical material is used to determine the distribution of natural features--forests, rivers, lakes--and the works of man. Useful sources of such information may include: road and topographical maps, aerial photographs, and even satellite photographs, particularly those from the LANDSAT (U.S. Geological Survey, 1974). The site-selection process is one that winnows out unsuitable regions and proceeds to fewer and smaller areas, so the photographs and maps will generally be used in an order that proceeds from those that depict very large areas, such as shown in LANDSAT photographs like Figure 8, to those that show smaller areas in greater detail, like the aerial photograph in Figure 9.

The climatological summaries of greatest use are the frequency distributions of wind speed and direction. This information will usually come in one of two forms. One of these is a tabulated joint frequency distribution like that shown in Table 4, an example of material that is available from the National Climatic Center. The wind rose is an easily interpreted graphical presentation of the directional frequencies. Examples of wind roses are shown in Figure 10, from the National Climatic Atlas (National Oceanic and Atmospheric Administration 1968). Other

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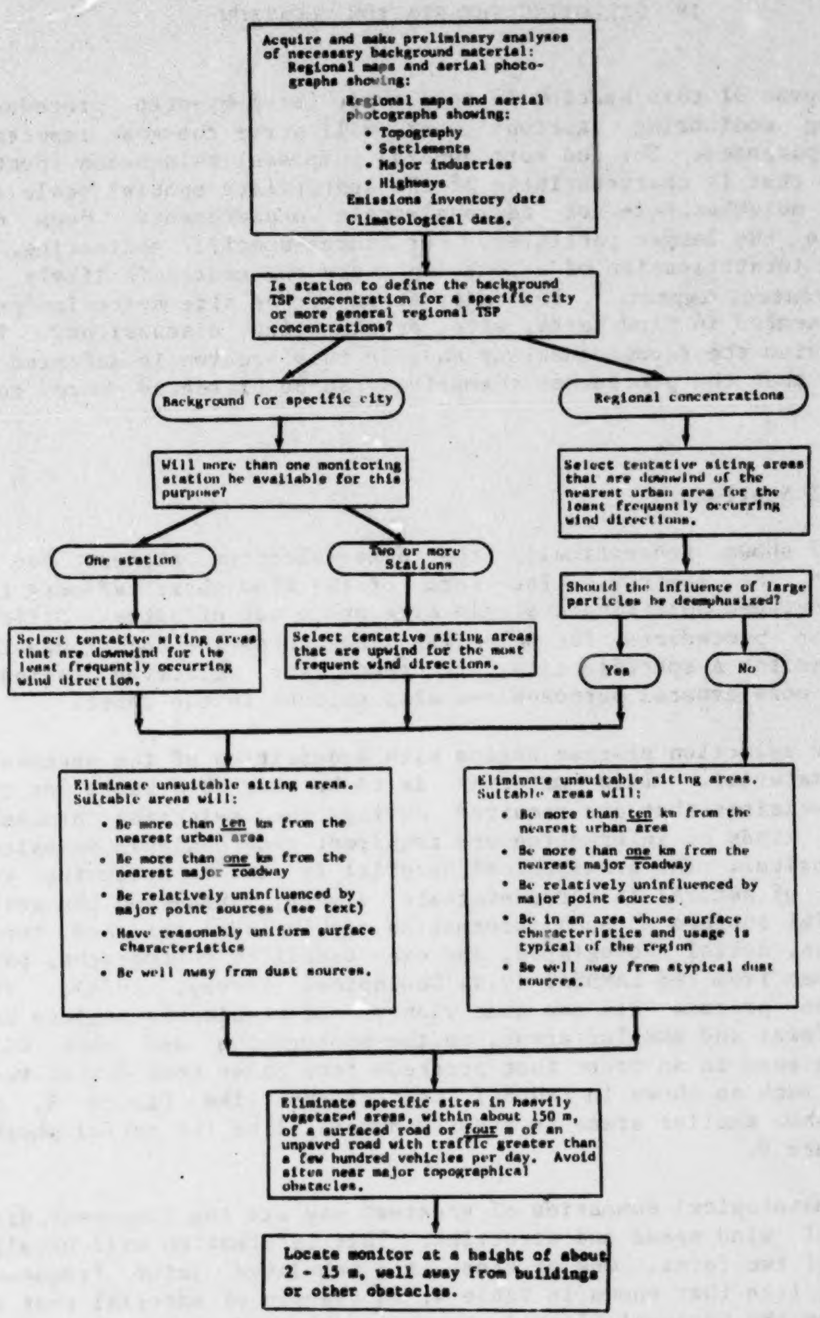
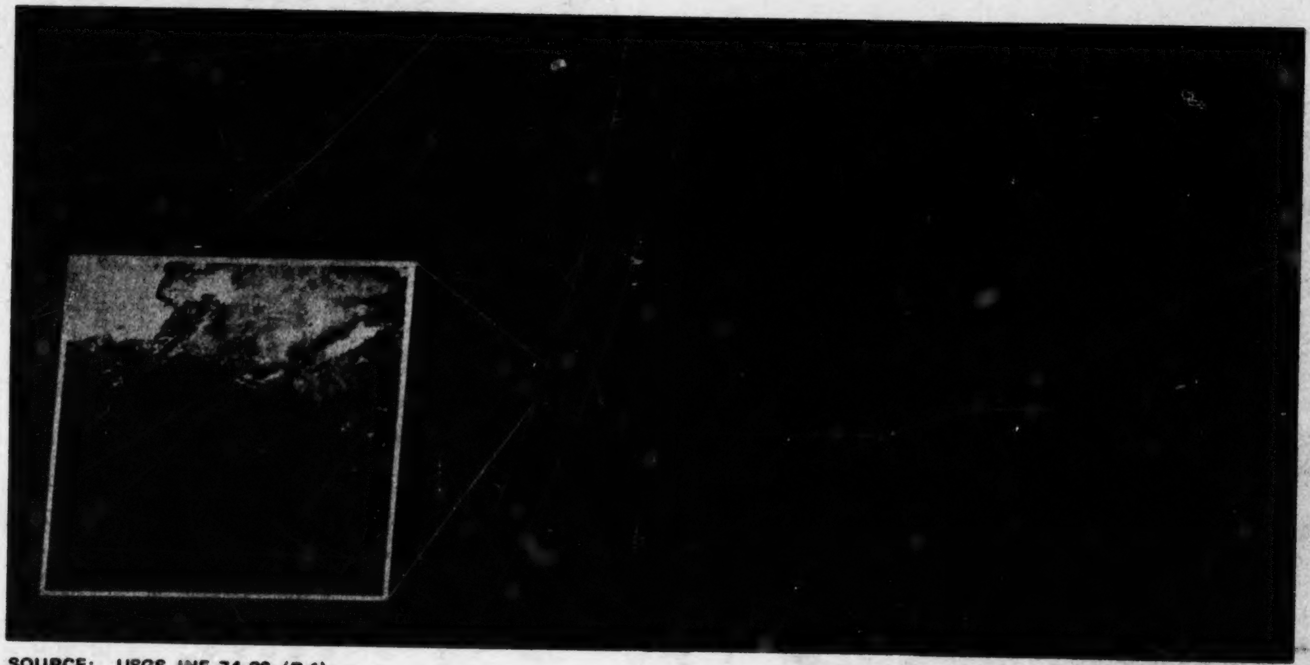

Acquire and make preliminary analyses of necessary background material:
Regional maps and aerial photographs showing:
Regional maps and aerial photographs showing:
• Topography
• Settlements
• Major industries
• Highways
Emissions inventory data
Climatological data.
Is station to define the background TSP concentration for a specific city or more general regional TSP concentrations?
Background for specific city
Regional concentrations
Will more than one monitoring station be available for this purpose?
One station
Two or more Stations
Select tentative siting areas that are downwind for the least frequently occurring wind direction.
Select tentative siting areas that are upwind for the most frequent wind directions.
Select tentative siting areas that are downwind of the nearest urban area for the least frequently occurring wind directions.
Should the influence of large particles be deemphasized?
Yes
No
Eliminate unsuitable siting areas. Suitable areas will:
• Be more than ten km from the nearest urban area
• Be more than one km from the nearest major roadway
• Be relatively uninfluenced by major point sources (see text)
• Have reasonably uniform surface characteristics
• Be well away from dust sources.
Eliminate unsuitable siting areas. Suitable areas will:
• Be more than ten km from the nearest urban area
• Be more than one km from the nearest major roadway
• Be relatively uninfluenced by major point sources.
• Be in an area whose surface characteristics and usage is typical of the region
• Be well away from atypical dust sources.
Eliminate specific sites in heavily vegetated areas, within about 150 m, of a surfaced road or four m of an unpaved road with traffic greater than a few hundred vehicles per day. Avoid sites near major topographical obstacles.
Locate monitor at a height of about 2 - 15 m, well away from buildings or other obstacles.

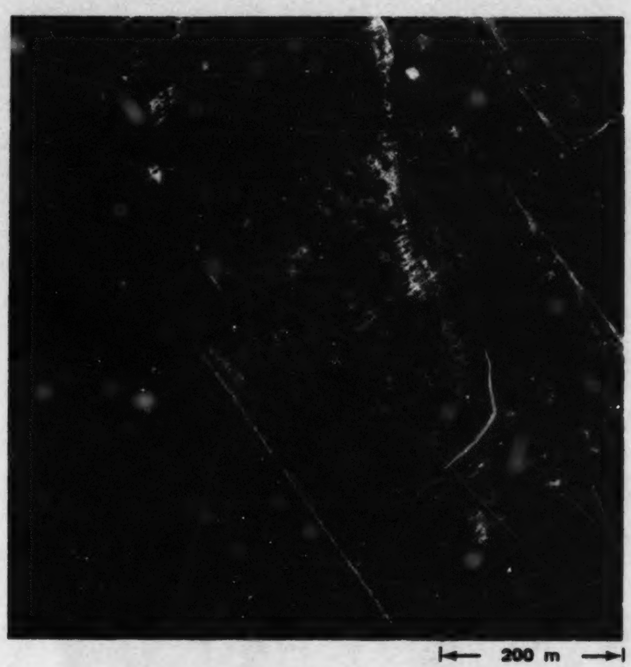
FIGURE 7 SCHEMATIC DIAGRAM OF A PROCEDURE FOR LOCATING REGIONAL MONITORING STATIONS



SOURCE: USGS INF-74-22 (R.1).

SA-3515-5

FIGURE 8 A SATELLITE (LANDSAT) PHOTOGRAPH AND A MOSAIC OF SUCH PHOTOGRAPHS



SOURCE: Dabberdt and Davis, 1974

FIGURE 9 AERIAL PHOTOGRAPH OF A RURAL AREA

types of useful climatological data are also available but, generally, are not as directly applicable to the site selection process as are the wind statistics.

Emissions inventories will be most useful for identifying large point sources of particulate that might otherwise be overlooked. The Environmental Protection Agency has a computerized National Emissions Data System (NEDS; see e.g., Bosch, 1975). All large point sources of a given pollutant, in this case TSP, greater than some specified source strength can be retrieved for a given area. Obviously, a list of large sources will be useful in the siting process so that proximity to large sources can be avoided. Figure 11 illustrates the kind of information provided by NEDS for each identified source. Countywide summaries of emissions from all stationary and mobile sources are also available from the NEDS inventory (Bosch, 1975).

After the background material has been assembled, a decision must be made regarding whether or not to use the monitor to supply information on TSP concentrations that enter a specific city. For selecting a purely regional site, maps or aerial photographs should be used to identify general areas that are suitable for locating such stations. Uniform topography and surface characteristics are desirable.

Table 4

EXAMPLE OF A TABULATED WIND SUMMARY

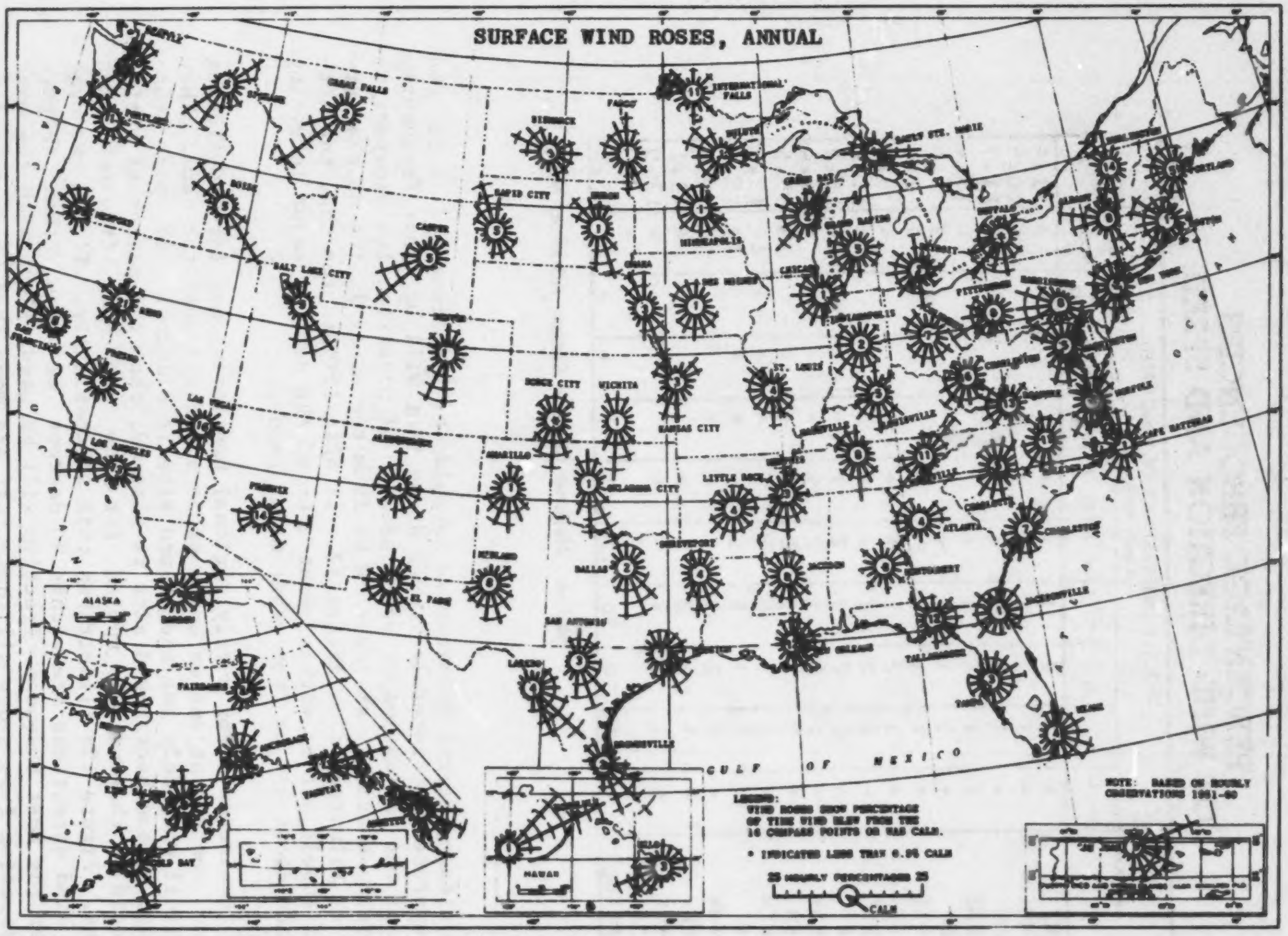
PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED:

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (IN MILES PER HOUR)										AV SPEED
	0 - 3	4 - 7	8 - 12	13 - 18	19 - 24	25 - 31	32 - 38	39 - 46	47 OVER	TOTAL	
N	+	1	2	1	+	+				4	11.4
NNE	+	1	2	1	+	+				4	10.5
NE	+	1	3	2	+	+				6	11.7
ENE	+	1	2	1	+					4	11.4
E	+	1	1	+	+					3	9.0
ESE	+	1	1	+						2	8.6
SE	+	1	2	1	+	+				4	8.9
SSE	+	1	2	1	+	+				4	11.0
S	1	2	2	3	2	1	+			10	13.3
SSW	+	1	1	3	2	1	+			8	14.4
SW	+	1	1	3	2	1	+	+		8	15.5
WSW	+	1	3	4	4	1	+	+	+	14	17.3
W	+	1	3	5	3	+	+	+		12	15.3
WNW	+	1	2	3	1	+	+			7	14.6
NW	+	1	2	2	1	+				6	13.1
NNW	+	1	1	1	+	+				4	12.0
CALM	+									+	
TOTAL	4	13	30	30	17	5	1	+	+	100	13.5

Source: National Climatic Center, Asheville, N.C.

The climatological information should be incorporated into the selection process to determine those areas that will be least frequently downwind of the closest major urban areas. If possible, the prospective siting areas should be at least 10 km from the outer limits of that urban area as illustrated in Figure 12. It also illustrates that the siting area should not be within about 1 km of the nearest major intercity freeway and about 1/2 km from other major roads.

The requirements for purely regional monitoring and for monitoring background concentrations entering urban areas are much the same. They are identical when only one background site is planned. If more than one upwind urban background site is planned, then the potential siting areas should be chosen to be upwind for the two most frequent wind directions. Figure 13a illustrates this schematically. If the two most frequent wind directions are within 90 degrees of each other (Figure 13b), then the most frequent direction will be used, along with the most common direction from among all those that are more than 90 degrees different from it. Figure 13b illustrates this. As noted before, any pro-


SURFACE WIND ROSES, ANNUAL
INTERNATIONAL FALLS
SAULT STE. MARIE
GREAT FALLS
RAPID CITY
CASPER
SALT LAKE CITY
DENVER
DODGE CITY
WICHITA
KANSAS CITY
ST. LOUIS
ALBUQUERQUE
AMARILLO
OKLAHOMA CITY
LITTLE ROCK
LAS VEGAS
LOS ANGELES
PHOENIX
EL PASO
DALLAS
SAN ANTONIO
NEW ORLEANS
JACKSONVILLE
MIAMI
BROWNSVILLE
CHICAGO
NEW YORK
PORTLAND
ALASKA
FAIRBANKS
HAWAII
GULF OF MEXICO
LEGEND:
WIND ROSES SHOW PERCENTAGE OF TIME WIND BLEW FROM THE 16 COMPASS POINTS OR WAS CALM.
• INDICATES LESS THAN 0.5% CALM
25 HOURLY PERCENTAGES 25
CALM
NOTE: BASED ON HOURLY OBSERVATIONS 1951-60

SOURCE: National Oceanographic and Atmospheric Administration, 1968

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FIGURE 10 EXAMPLE OF WIND ROSES

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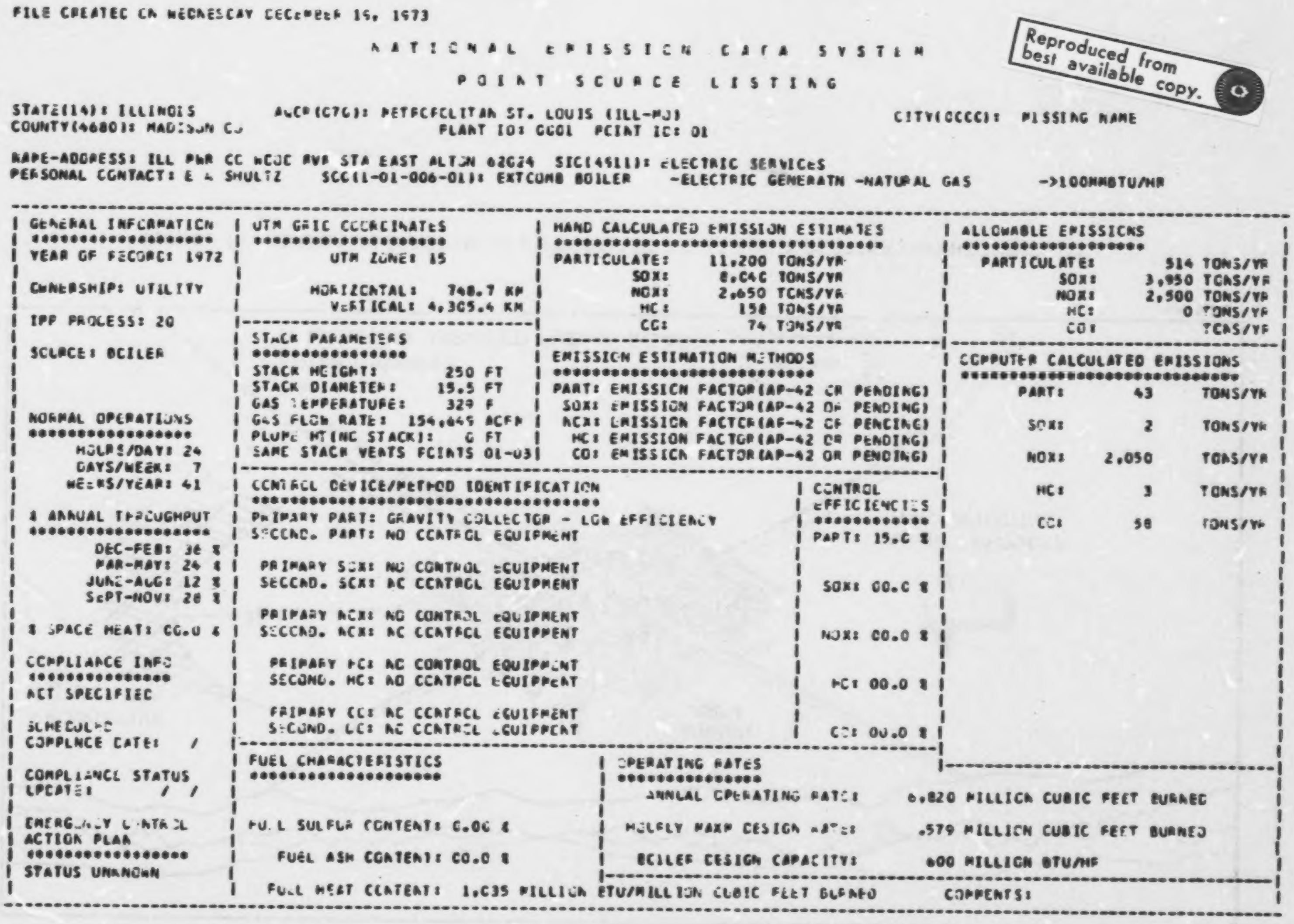

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FILE CREATED ON WEDNESDAY DECEMBER 19, 1973

                         N A T I O N A L   E M I S S I O N   D A T A   S Y S T E M

                                        P O I N T   S O U R C E   L I S T I N G

STATE(14): ILLINOIS          AQCR(070): METROPOLITAN ST. LOUIS (ILL-MO)                              CITY(0000):  MISSING NAME
COUNTY(4680): MADISON CO                              PLANT ID: 0001  POINT ID: 01

NAME-ADDRESS: ILL PWR CO WOOD RVR STA EAST ALTON 62024  SIC(4911): ELECTRIC SERVICES
PERSONAL CONTACT: E A SHULTZ     SCC(1-01-006-01): EXTCOMB BOILER    -ELECTRIC GENERATN -NATURAL GAS        ->100MMBTU/HR

---------------------------------------------------------------------------------------------------------------------------
| GENERAL INFORMATION  | UTM GRID COORDINATES        | HAND CALCULATED EMISSION ESTIMATES     | ALLOWABLE EMISSIONS                 |
| ******************** | **********************      | ************************************** | *********************               |
| YEAR OF RECORD: 1972 |         UTM ZONE: 15        | PARTICULATE:     11,200 TONS/YR        |   PARTICULATE:        514 TONS/YR |
|                      |                             |         SOX:      8,040 TONS/YR        |           SOX:      3,950 TONS/YR |
| OWNERSHIP: UTILITY   |      HORIZONTAL:   748.7 KM |         NOX:      2,650 TONS/YR        |           NOX:      2,500 TONS/YR |
|                      |        VERTICAL: 4,305.4 KM |          HC:        158 TONS/YR        |            HC:          0 TONS/YR |
| IPP PROCESS: 20      |-----------------------------|          CO:         74 TONS/YR        |            CO:            TONS/YR |
|                      | STACK PARAMETERS            |----------------------------------------|-------------------------------------|
| SOURCE: BOILER       | ****************            | EMISSION ESTIMATION METHODS            | COMPUTER CALCULATED EMISSIONS       |
|                      | STACK HEIGHT:       250 FT  | ****************************           | *****************************       |
|                      | STACK DIAMETER:    15.5 FT  | PART: EMISSION FACTOR(AP-42 OR PENDING) |        PART:      43      TONS/YR  |
|                      | GAS TEMPERATURE:    329 F   |  SOX: EMISSION FACTOR(AP-42 OR PENDING) |                                    |
| NORMAL OPERATIONS    | GAS FLOW RATE:  154,649 ACFM |  NOX: EMISSION FACTOR(AP-42 OR PENDING) |        SOX:        2      TONS/YR  |
| ******************   | PLUME HT(INC STACK):   0 FT  |   HC: EMISSION FACTOR(AP-42 OR PENDING) |                                    |
|      HOURS/DAY: 24   | SAME STACK VENTS POINTS 01-03|   CO: EMISSION FACTOR(AP-42 OR PENDING) |        NOX:    2,050      TONS/YR  |
|      DAYS/WEEK:  7   |---------------------------------------------------------------------|                                    |
|     WEEKS/YEAR: 41   | CONTROL DEVICE/METHOD IDENTIFICATION                | CONTROL        |         HC:        3      TONS/YR  |
|                      | ************************************                | EFFICIENCIES   |                                    |
| % ANNUAL THROUGHPUT  | PRIMARY PART: GRAVITY COLLECTOR - LOW EFFICIENCY     | ************   |         CO:       58      TONS/YR  |
| ******************** | SECOND. PART: NO CONTROL EQUIPMENT                   | PART: 15.0 %   |                                    |
|       DEC-FEB: 36 %  |                                                      |                |                                    |
|       MAR-MAY: 24 %  |  PRIMARY SOX: NO CONTROL EQUIPMENT                   |                |                                    |
|      JUNE-AUG: 12 %  |  SECOND. SOX: NO CONTROL EQUIPMENT                   |  SOX: 00.0 %   |                                    |
|      SEPT-NOV: 28 %  |                                                      |                |                                    |
|                      |  PRIMARY NOX: NO CONTROL EQUIPMENT                   |                |                                    |
| % SPACE HEAT: 00.0 % |  SECOND. NOX: NO CONTROL EQUIPMENT                   |  NOX: 00.0 %   |                                    |
|                      |                                                      |                |                                    |
| COMPLIANCE INFO      |   PRIMARY HC: NO CONTROL EQUIPMENT                   |                |                                    |
| ***************      |   SECOND. HC: NO CONTROL EQUIPMENT                   |   HC: 00.0 %   |                                    |
| ACT SPECIFIED        |                                                      |                |                                    |
|                      |   PRIMARY CO: NO CONTROL EQUIPMENT                   |                |                                    |
| SCHEDULED            |   SECOND. CO: NO CONTROL EQUIPMENT                   |   CO: 00.0 %   |                                    |
| COMPLNCE DATE:    /  |---------------------------------------------------------------------|                                    |
|                      | FUEL CHARACTERISTICS               | OPERATING RATES                                |------------------------------------|
| COMPLIANCE STATUS    | ********************               | ***************                                                                       |
| UPDATE:         / /  |                                    |    ANNUAL OPERATING RATE:     6,820 MILLION CUBIC FEET BURNED                       |
|                      |                                    |                                                                                       |
| EMERGENCY CONTROL    | FUEL SULFUR CONTENT: 0.00 %        |  HOURLY MAXM DESIGN RATE:      .579 MILLION CUBIC FEET BURNED                       |
| ACTION PLAN          |                                    |                                                                                       |
| ******************   |   FUEL ASH CONTENT: 00.0 %         |   BOILER DESIGN CAPACITY:       600 MILLION BTU/HR                                  |
| STATUS UNKNOWN       |                                    |---------------------------------------------------------------------------------------|
|                      |  FUEL HEAT CONTENT:  1,035 MILLION BTU/MILLION CUBIC FEET BURNED        COMMENTS:                                 |
---------------------------------------------------------------------------------------------------------------------------
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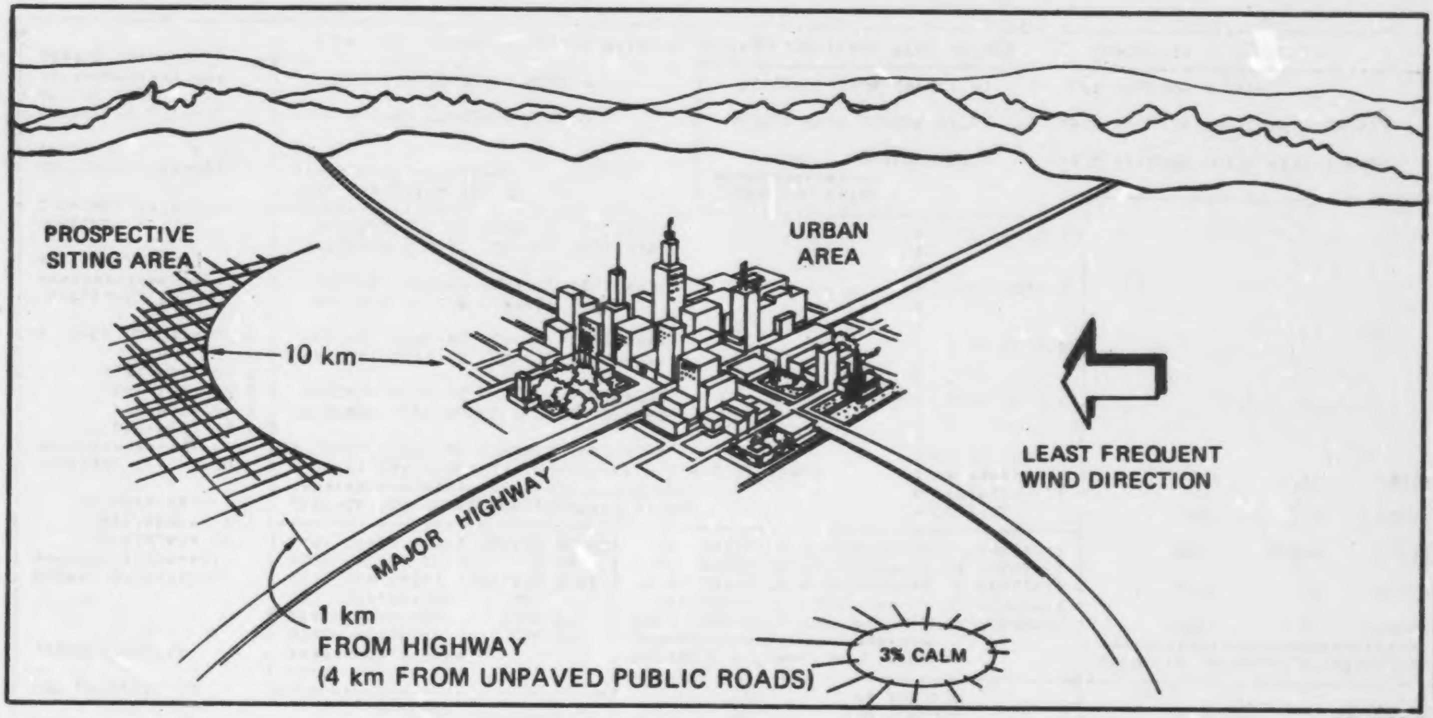
FIGURE 15 AN EXAMPLE OF OUTPUT FROM THE NATIONAL CLIMATIC CENTER'S STAR PROGRAM


PROSPECTIVE SITING AREA
URBAN AREA
10 km
LEAST FREQUENT WIND DIRECTION
MAJOR HIGHWAY
1 km
FROM HIGHWAY
(4 km FROM UNPAVED PUBLIC ROADS)
3% CALM

SA-3515-7

FIGURE 12 SCHEMATIC DIAGRAM OF APPROPRIATE AREAS FOR A REGIONAL MONITORING SITE

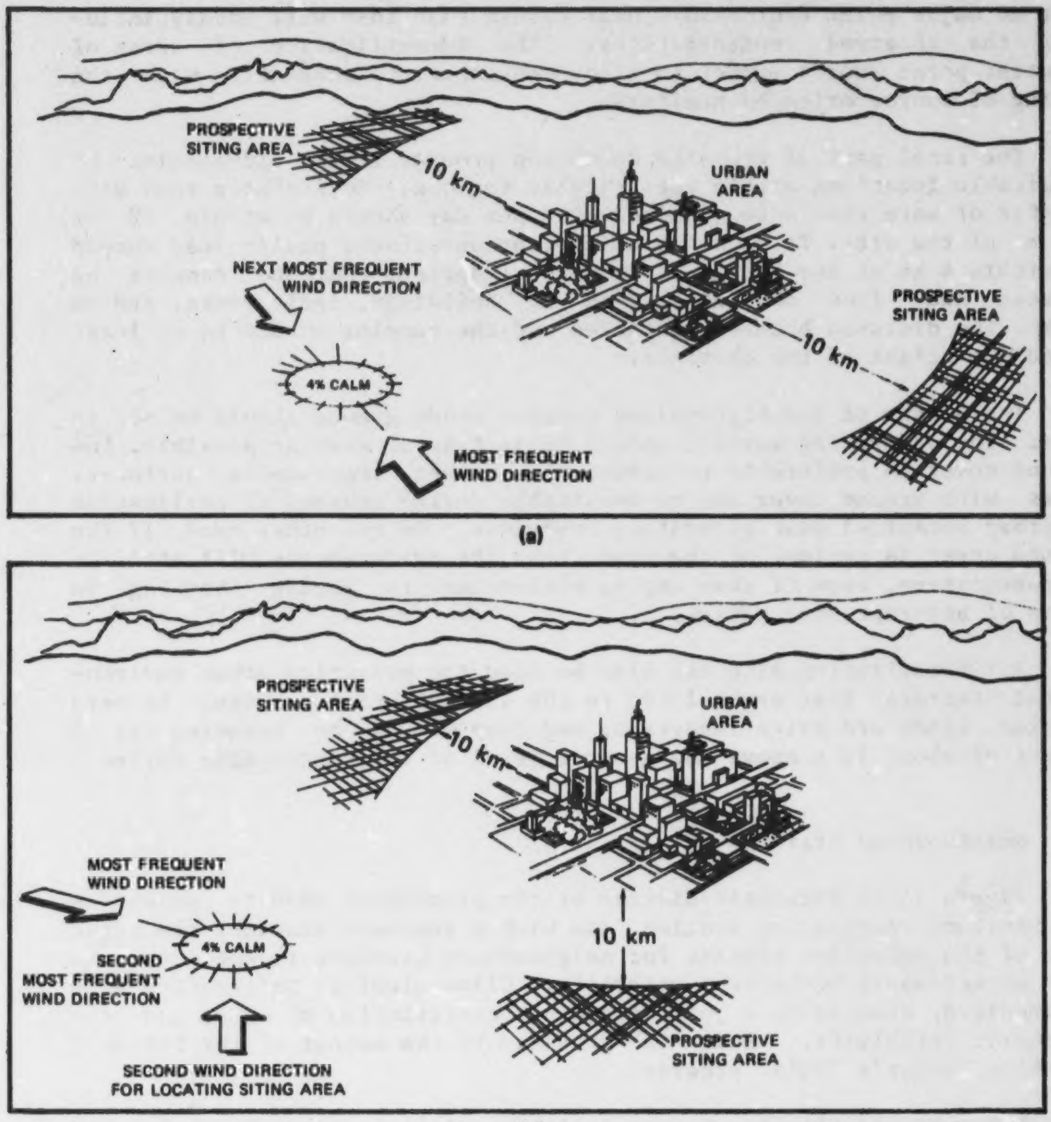

PROSPECTIVE SITING AREA
10 km
URBAN AREA
NEXT MOST FREQUENT WIND DIRECTION
PROSPECTIVE SITING AREA
10 km
4% CALM
MOST FREQUENT WIND DIRECTION
(a)
PROSPECTIVE SITING AREA
URBAN AREA
10 km
MOST FREQUENT WIND DIRECTION
4% CALM
SECOND MOST FREQUENT WIND DIRECTION
10 km
PROSPECTIVE SITING AREA
SECOND WIND DIRECTION FOR LOCATING SITING AREA
(b)
SA-3515-8

FIGURE 13 SCHEMATIC DIAGRAMS OF APPROPRIATE SITING AREAS FOR REGIONAL MONITORS WHEN TWO SITES ARE PLANNED

spective siting area should be more than 1 km from the nearest major intercity arterial road. The emissions survey should be used to ensure that no major point sources are near enough that they will unduly influence the observed concentrations. The identification of areas of greatest point source impact is discussed later, in connection with the siting of source oriented monitors.

The final part of the site selection process is the elimination of unsuitable locations within the suitable regions. No surfaced road with traffic of more than a few hundred cars per day should be within 40 or 50 m of the site. If at all possible, no unsurfaced public road should be within 4 km of the site. It is quite important that the sampler be located away from obstacles such as buildings, large trees, and so forth. The distance between obstacles and the sampler should be at least twice the height of the obstacle.

The height of the high-volume sampler above ground should be 2 to 15 m. The underlying surface should be as free of dust as possible. Low ground cover is preferable to pavement or other impermeable surfaces. Sites with ground cover may be unsuitable during seasons of pollination or other botanical dust generating processes. On the other hand, if the ground cover is typical of the area, then the measurements will still be representative, even if they may be misleading to anyone thinking in terms of anthropogenic causes.

A TSP-monitoring site can also be used for measuring other environmental factors that are related to the air pollution problem. In particular, winds are quite important, and they should be measured at a height of about 10 m above the general level of the surrounding surface.

B. Neighborhood Stations

Figure 14 is schematic diagram of the procedures used to select a neighborhood monitoring station. As with a regional station, the first step of the selection process for neighborhood stations is the acquisition of necessary background materials. Climatological information will be required, especially a joint frequency distribution of winds and atmospheric stability. This is provided by the output of the National Climatic Center's "STAR" program.

The National Climatic Center is located in Asheville, North Carolina. Figure 15 provides an example of the type of information generated by the STAR program. Relative frequencies of occurrence such as those shown in Figure 15 for Pasquill's (1961) neutral stability, are available for each of the other stability classes. The results given in Figure 15 are derived from springtime (March, April, May) data, but similar information can be produced for monthly or annual frequency distributions. The National Climatic Center also provides the output on punched cards suitable for use with the Climatological Dispersion Model (CDM; Busse and Zimmerman, 1973).

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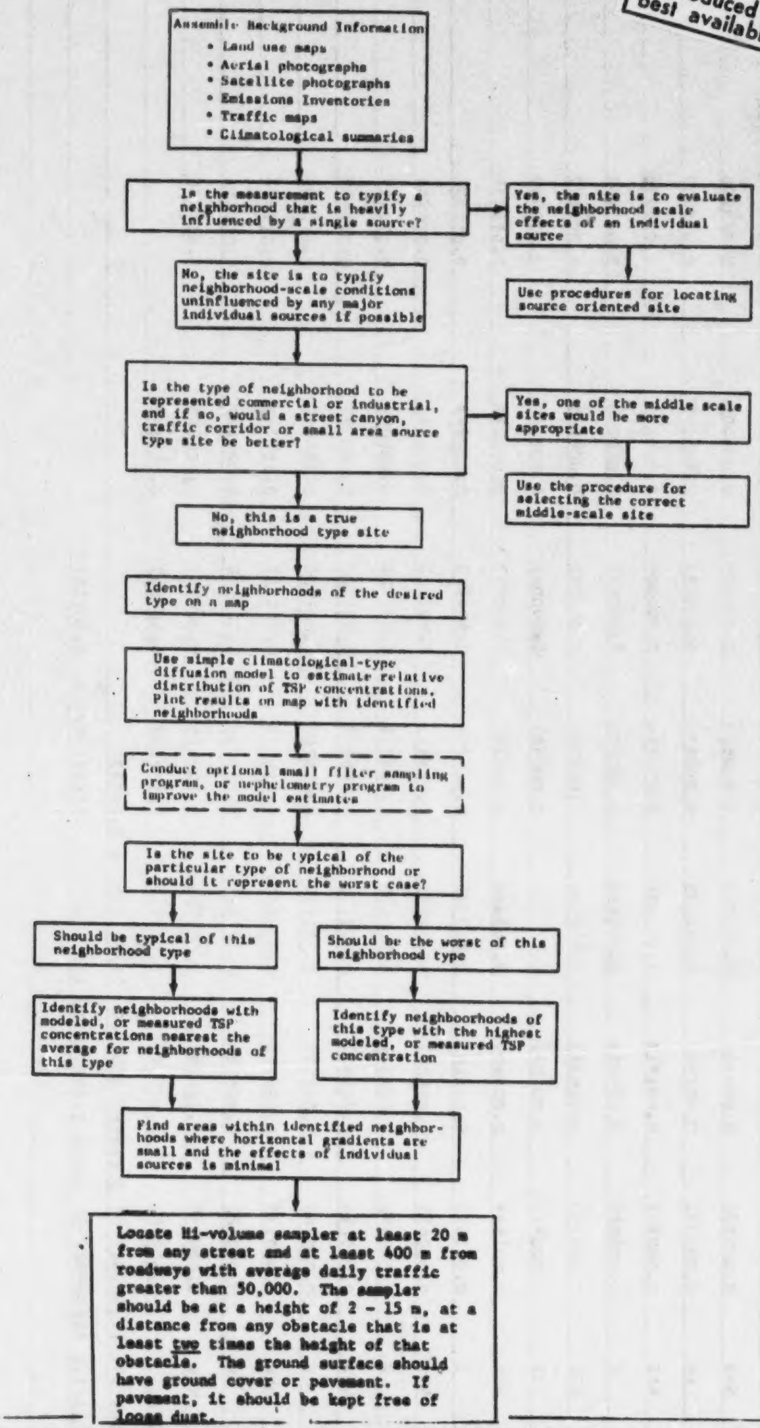
Assemble Background Information
• Land use maps
• Aerial photographs
• Satellite photographs
• Emissions Inventories
• Traffic maps
• Climatological summaries
Is the measurement to typify a neighborhood that is heavily influenced by a single source?
Yes, the site is to evaluate the neighborhood scale effects of an individual source
Use procedures for locating source oriented site
No, the site is to typify neighborhood-scale conditions uninfluenced by any major individual sources if possible
Is the type of neighborhood to be represented commercial or industrial, and if so, would a street canyon, traffic corridor or small area source type site be better?
Yes, one of the middle scale sites would be more appropriate
Use the procedure for selecting the correct middle-scale site
No, this is a true neighborhood type site
Identify neighborhoods of the desired type on a map
Use simple climatological-type diffusion model to estimate relative distribution of TSP concentrations. Plot results on map with identified neighborhoods
Conduct optional small filter sampling program, or nephelometry program to improve the model estimates
Is the site to be typical of the particular type of neighborhood or should it represent the worst case?
Should be typical of this neighborhood type
Should be the worst of this neighborhood type
Identify neighborhoods with modeled, or measured TSP concentrations nearest the average for neighborhoods of this type
Identify neighboorhoods of this type with the highest modeled, or measured TSP concentration
Find areas within identified neighborhoods where horizontal gradients are small and the effects of individual sources is minimal
Locate Hi-volume sampler at least 20 m from any street and at least 400 m from roadways with average daily traffic greater than 50,000. The sampler should be at a height of 2 - 15 m, at a distance from any obstacle that is at least two times the height of that obstacle. The ground surface should have ground cover or pavement. If pavement, it should be kept free of loose dust.

FIGURE 14 SCHEMATIC DIAGRAM OF A PROCEDURE FOR LOCATING NEIGHBORHOOD MONITORING STATIONS

```
        SEA= MAM                 RELATIVE FREQUENCY DISTRIBUTION          STATION #13882 CHATTANOOGA, TN 24 OBS 1960-64

                                                  SPEED(KTS)
DIRECTION      0 - 3        4 - 6        7 - 10       11 - 16      17 - 21    GREATER THAN 21        TOTAL
     N      0.000912     0.002719     0.004079     0.007614     0.000725      0.000000            0.016048
   NNE      0.000800     0.004169     0.006888     0.010605     0.000634      0.000000            0.023096
    NE      0.000731     0.002900     0.002175     0.003535     0.000181      0.000000            0.009523
   ENE      0.000385     0.001813     0.000634     0.000544     0.000000      0.000000            0.003376
     E      0.000069     0.001269     0.000453     0.000091     0.000000      0.000000            0.001882
   ESE      0.000245     0.000997     0.000544     0.000091     0.000000      0.000000            0.001877
    SE      0.000919     0.001088     [illegible]  0.000453     0.000091      0.000000            0.003729
   SSE      0.001449     0.003807     0.005348     0.006707     0.000997      0.000272            0.018579
     S      0.001386     0.006163     0.017765     0.026194     0.004260      0.000363            0.056131
   SSW      0.000655     0.003263     0.006526     0.014411     0.001903      0.000181            0.026940
    SW      0.000696     0.002266     0.003625     0.004713     0.000725      0.000091            0.012117
   WSW      0.000280     0.001631     0.002175     0.006617     0.001722      0.000997            0.013422
     W      0.000160     0.001178     0.001994     0.005962     0.001088      0.000906            0.011308
   WNW      0.000135     0.000725     0.003807     0.010333     0.003625      0.001269            0.019894
    NW      0.000422     0.000725     0.001269     0.005529     0.002538      0.001178            0.011661
   NNW      0.000547     0.001269     0.003928     0.009426     0.002357      0.000363            0.017949
TOTAL       0.009789     0.035983     0.062449     0.112843     0.020847      0.005620
RELATIVE FREQUENCY OF OCCURRENCE OF  D  STABILITY  = 0.247530
RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH  D  STABILITY  =  0.002357
                           (NEUTRAL / DAY)
```

FIGURE 11   EXAMPLE OF A NEDS OUTPUT FOR A POINT SOURCE

Aerial photographs and topographic maps will be quite useful to determine the distribution of land use through the city. Special maps, showing the details of land use, are sometimes available for study in planning agency offices. Figure 16 shows a section from a map of this type produced by the Sanborn Map Company.*

Another valuable type of map is the traffic map. Figure 17 is an example of this kind of data. Traffic data are available in several forms, but the information itself is usually limited to the average numbers of cars per day on a given section of roadway. Ludwig and Kealoha (1975) have presented a brief summary of the usual types and forms of traffic data that are available. They also discuss sources of other kinds of data, e.g., land use, climatological, and so forth.

Emissions inventories are another important type of background information that must be assembled during the initial stage of the site selection process. The NEDS data have already been cited (see Figure 11) and they provide valuable information concerning the larger point sources, but the spatial resolution for area sources is not usually any finer than county size. The area source emissions must be distributed into smaller areas where possible. Sometimes this must be done rather crudely--for example, on the basis of population or housing units. Population and housing data are available for the census tracts within 241 Standard Metropolitan Statistical Areas (SMSA). Figure 18, from one of these Bureau of the Census (1972) documents, shows the size of some tracts. In general, the tracts are smaller in areas of dense population than in less densely populated regions. The Office of Air Quality Planning and Standards of EPA** has prepared computer programs that will apportion area source emissions from the NEDS into gridded areas according to population.

Before proceeding with the site selection process, it is necessary to answer two questions. First, is the site being established to determine the impact of a specific major source on the neighborhood? If so, then the procedures used for locating source-oriented sites would be more suitable. The procedures for selecting source-oriented sites are discussed in a later section of this report. The second question relates to scale. If the purpose does not require characterization of conditions throughout a neighborhood, then the procedures for selecting middle scale sites would be more appropriate.

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* Sanborn Map Company, 629 5th Avenue, Pelham, New York 10803

** Mr. J. Mersch, EPA, Research Triangle Park, N.C., personal communication.

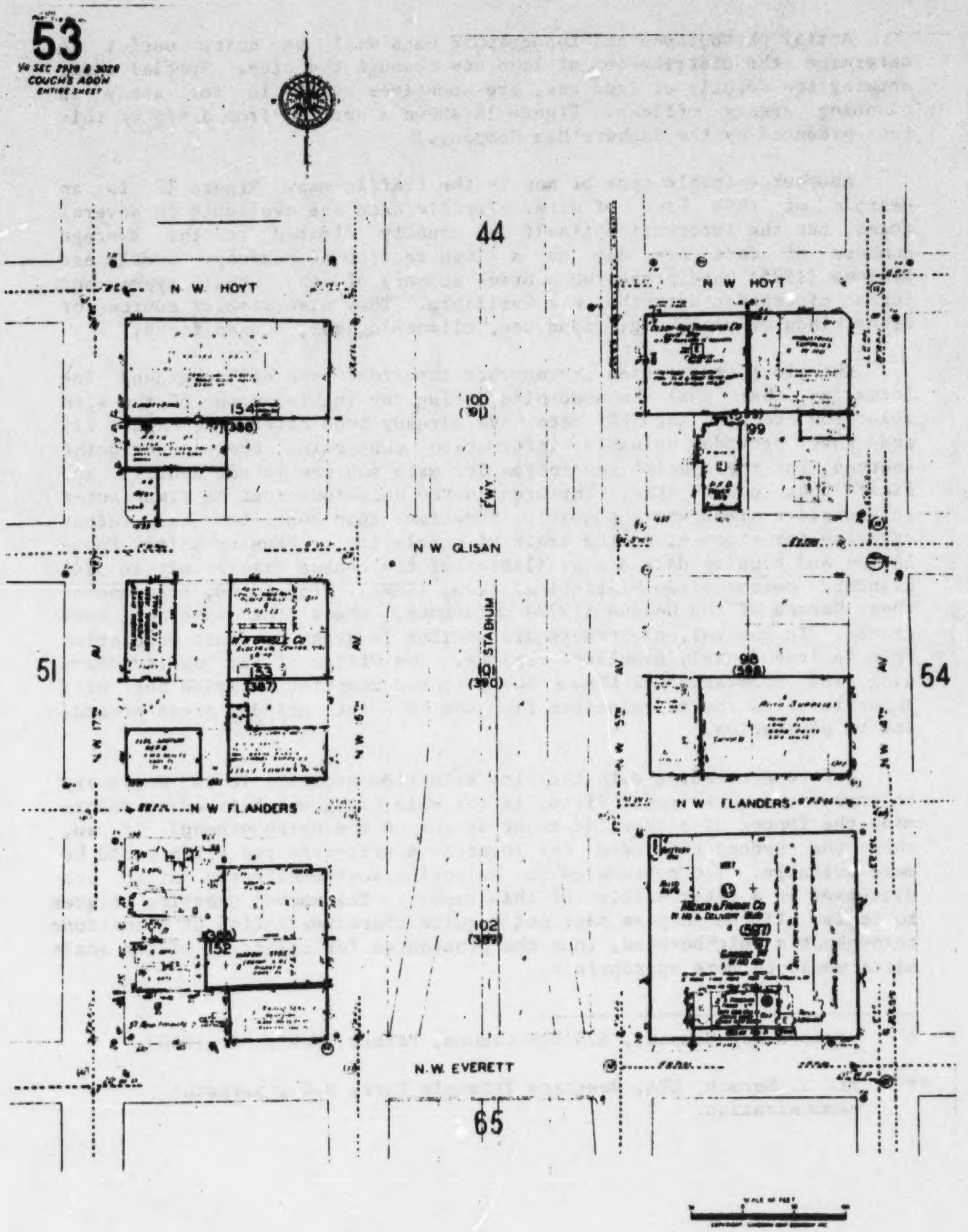
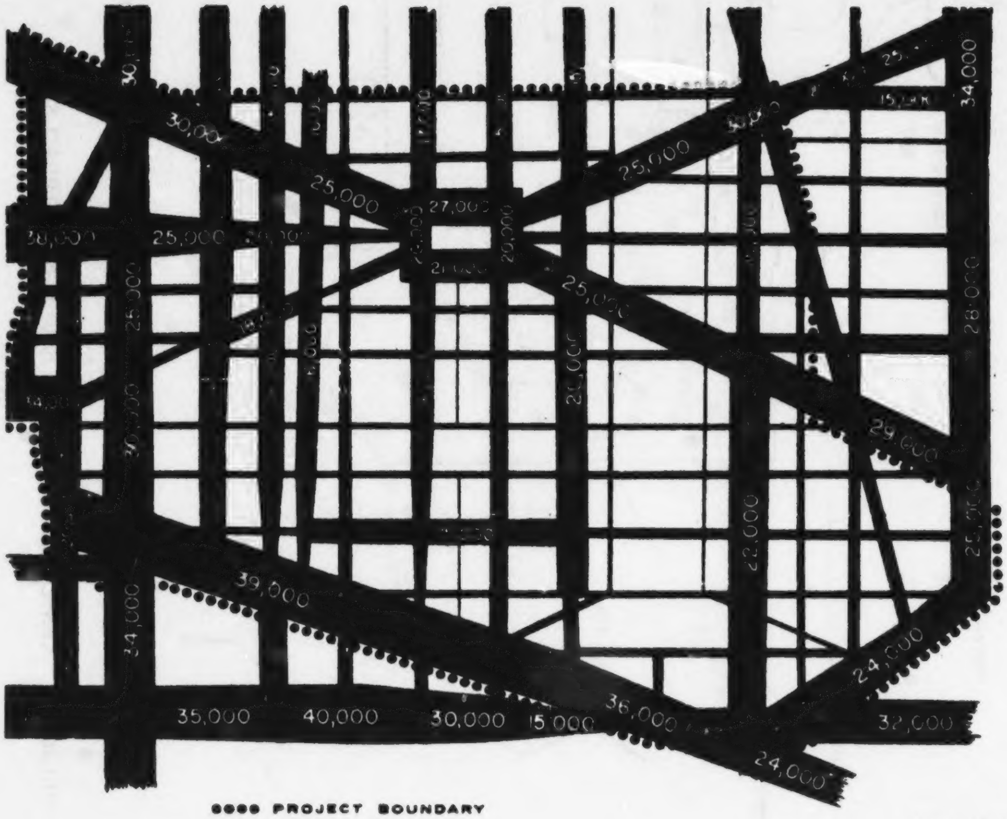

53
1/4 SEC 2929 & 3029
COUCH'S ADDN
ENTIRE SHEET
44
N. W. HOYT
N W HOYT
154
(386)
100
(391)
99
FWY
N W GLISAN
STADIUM
51
153
(387)
101
(390)
98
(388)
54
N W FLANDERS
152
102
(389)
N.W. EVERETT
65

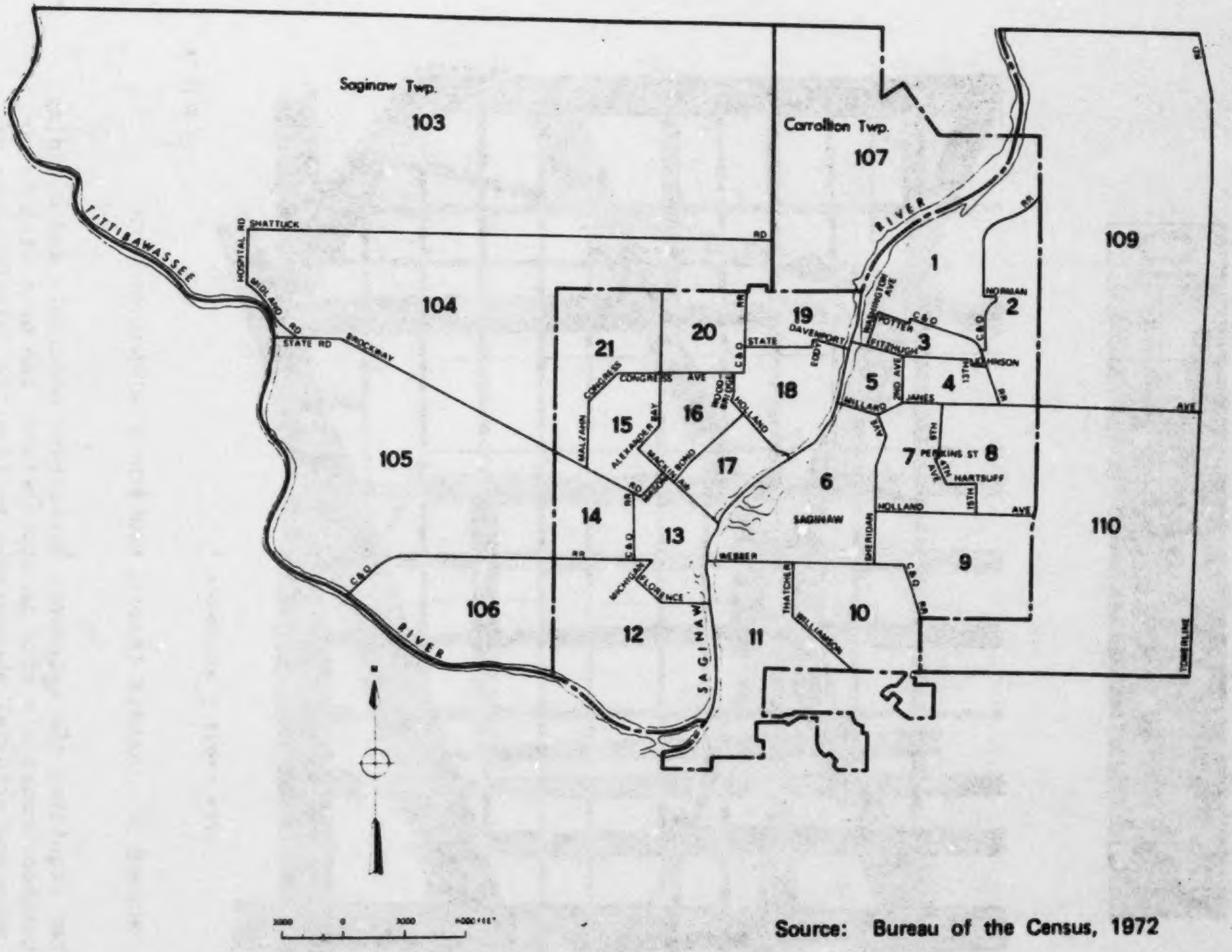
FIGURE 16 A SANBORN MAP FOR A SECTION OF PORTLAND, OREGON


30,000
30,000
25,000
27,000
25,000
38,000
25,000
20,000
25,000
15,000
34,000
28,000
29,000
22,000
39,000
34,000
24,000
35,000
40,000
30,000
15,000
36,000
32,000
24,000
●●●● PROJECT BOUNDARY

SA-3515-18

FIGURE 17 SAMPLE TRAFFIC MAP FOR A DOWNTOWN AREA

After acquiring the necessary background materials and deciding that a neighborhood scale site is appropriate, the next step is to use the maps and arterial photographs to identify neighborhoods of the type that are of concern to the particular monitoring objective. Figure 19 shows aerial photographs of two different kinds of residential neighborhood. Figure 19a shows an area that was built more recently than that shown in Figure 19b, with its more mature trees and shrubbery. Figure 20 shows a section of a topographic map corresponding to Figure 19b.


Saginaw Twp.
103
Carrollton Twp.
107
109
110
104
105
106
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
TITTIBAWASSEE
RIVER
SAGINAW
RIVER
SAGINAW
SHATTUCK
RD
HOSPITAL RD
MIDLAND RD
STATE RD
BROCKWAY
CONGRESS AVE
MALZAHN
ALEXANDER BAY
MACKINAW
BOND
HOLLAND
STATE
DAVENPORT
FITZHUGH
POTTER
WASHINGTON AVE
NORMAN
JAMES
2ND AVE
13TH
PERKINS ST
HARTSUFF
15TH
HOLLAND AVE
SHERIDAN
THATCHER
WILLIAMSON
WEBBER
FLORENCE
MICHIGAN
C&O
RR
AVE
TOWNLINE
RD
3000
0
3000
6000 FEET

Source: Bureau of the Census, 1972

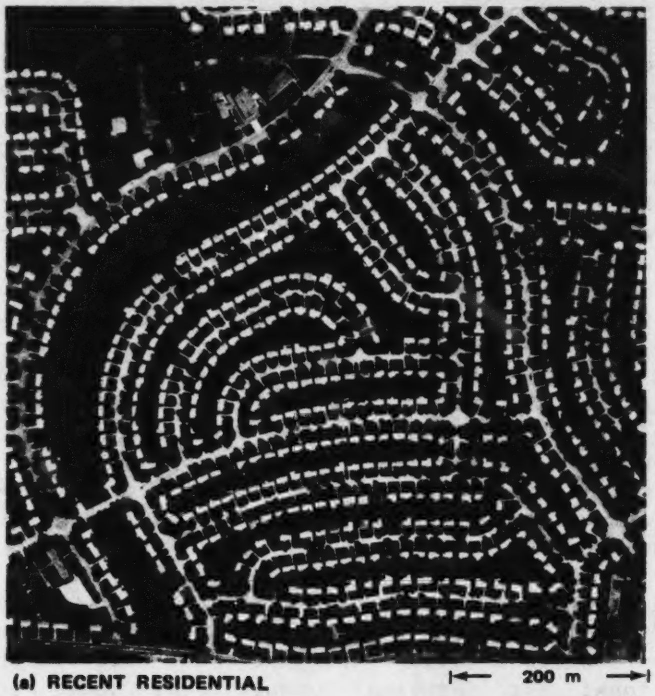
FIGURE 18 CENSUS TRACTS IN THE SAGINAW, MICHIGAN SMSA

After potentially suitable TSP-monitoring neighborhoods have been identified on a map, a simple numerical simulation model should be applied to provide an estimate of annual or seasonal average TSP concentration throughout the city. Several suitable models are available. Probably the climatological dispersion model (CDM; Busse and Zimmerman, 1973) would be easiest to apply; its required inputs are the output of the STAR program referred to earlier and an inventory of point source and gridded area source emissions. Although the use of the computer model is most desirable, the gridded emissions inventory could be used to identify neighborhoods where the distributed sources have their greatest impact because concentrations are generally closely related to nearby ground level emissions. Areas strongly influenced by large elevated sources will be exceptions to this rule. The model given in Appendix A of this report could be used to identify the areas of greatest influence for the largest sources. The graphs and methods given by Turner (1969) could be applied for the more frequently occurring combinations of wind and stability if the facilities for using the model in Appendix A are not available.

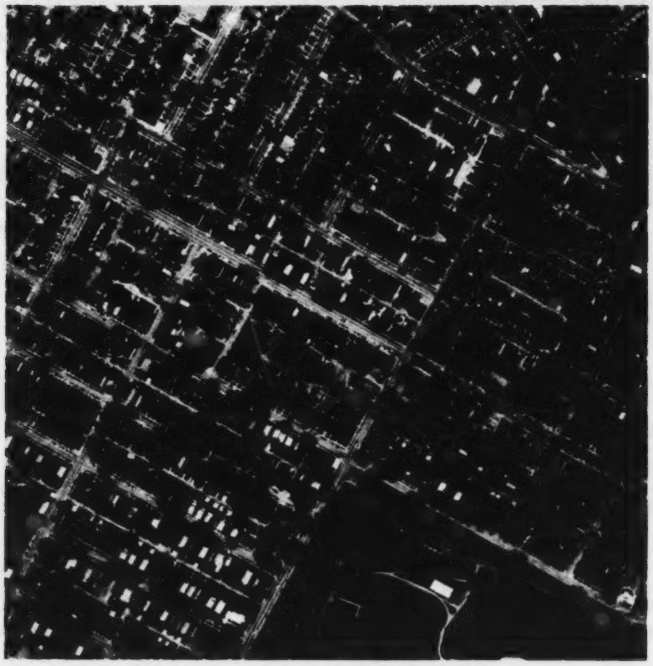
If time and resources are available, a limited sampling program would be highly desirable to provide better data on the relative concentrations in the various candidate neighborhoods. Studies in connection with the National Air Sampling Network (U.S. Public Health Service, 1958) concluded that biweekly (alternate weeks) sampling, randomized with respect to day of the week, would define median TSP concentrations sufficiently well.

Thus, a limited sampling program would be justified. Furthermore, it might be sufficient to use nonstandard sampling methods for this purpose. For example, smaller pumps with smaller filters would be more portable and easier to use for preliminary studies. Another approach to the problem of a preliminary particulate survey might employ a nephelometer, moved from one location to another during the sampling period. The nephelometer measures light scattering which is related to particulate concentration (Charlson et al., 1969).

Once the spatial distribution of TSP concentration has been estimated from modeling, a preliminary survey, or from a combination of the two methods, then it should be superimposed on the map showing the locations of the candidate neighborhoods. If the objective of the monitoring is to obtain data for the particular neighborhood that is likely to have the highest average TSP concentrations among all the neighborhoods of the chosen type, the measured or modeled spatial distribution will serve to identify the appropriate area. Similarly, the distribution of average TSP concentration can be used to judge which of the candidate neighborhoods is nearest the average for all of them.



(a) RECENT RESIDENTIAL



(b) OLDER NEIGHBORHOOD WITH MATURE TREES

SOURCE: Dabberdt and Davis, 1974

FIGURE 19 AERIAL PHOTOGRAPHS OF URBAN RESIDENTIAL NEIGHBORHOODS

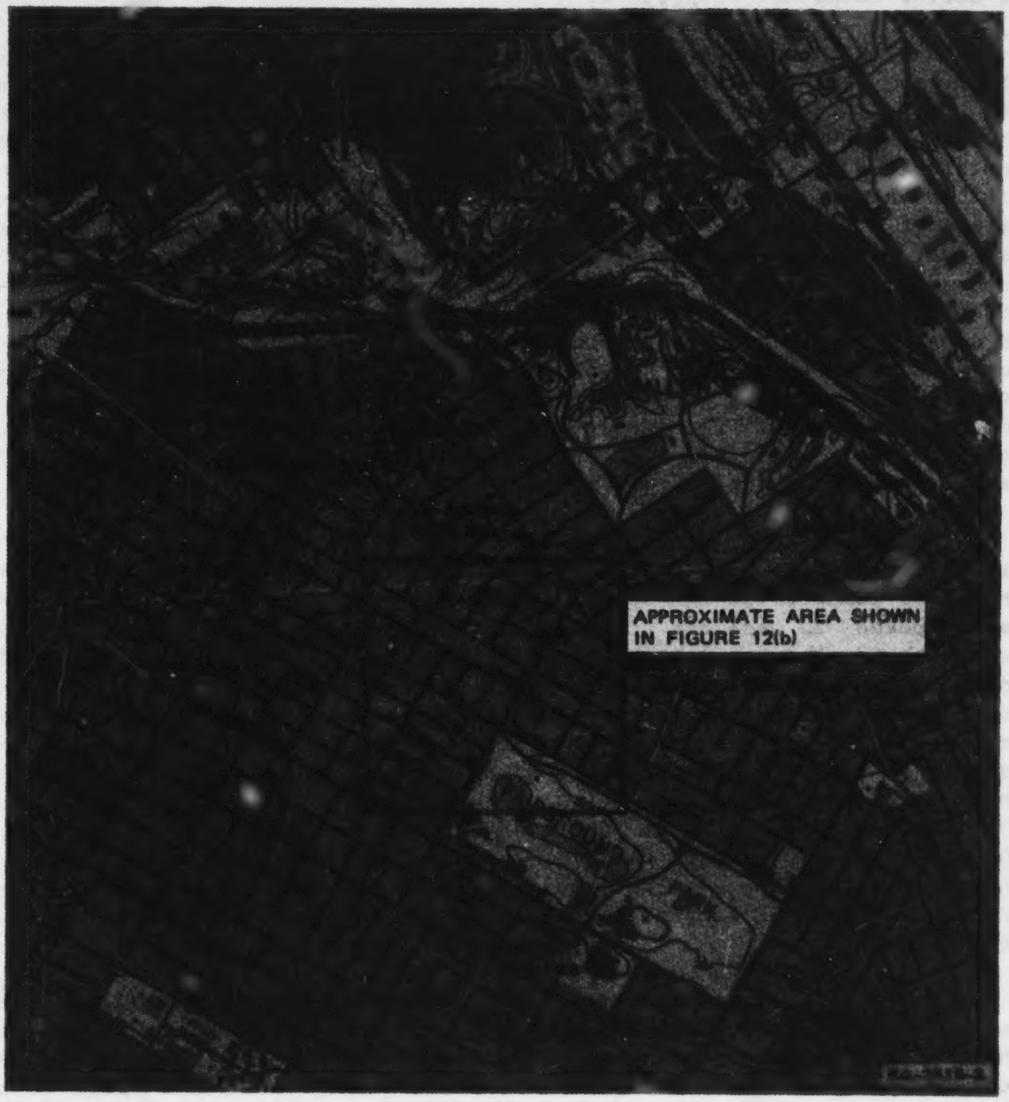

APPROXIMATE AREA SHOWN IN FIGURE 12(b)

FIGURE 20 A TYPICAL URBAN NEIGHBORHOOD DEPICTED ON A TOPOGRAPHICAL MAP

The above discussion represents rather minimal preparatory efforts in the site selection process. Obviously, modeling is subject to considerable uncertainty, which can be reduced by a limited sampling program. Even the limited sampling program provides only estimates of average concentrations, and averages do not allow as complete a comparison among sites as would be desirable. A more extensive sampling program could determine more reliable frequency distributions, which would be better bases for comparison.

Once the neighborhoods that most nearly meet the monitoring objective have been identified, then more specific locations must be selected. These locations must be at least 400 m from the nearest highway carrying 50,000 or more vehicles per day. This spacing should limit the contribution of the roadway to less than about 7 or 8 $\mu g\ m^{-3}$. Lower traffic volumes will allow for closer spacing. An example of the calculation of a roadway's contribution is presented in Section IV. The inlet must be at least 100 m from any local street having daily traffic of about 20,000 vehicles. The sampler should be at least 20 m from neighborhood streets with traffic of 2000 vehicles per day or less. A limited sampling program could be undertaken to define gradients (especially horizontal) in the area. A nephelometer would be particularly appropriate for this purpose. If the gradients are very strong, then a location more distant from the nearest street might be required. Conversely, weak gradients would allow closer placement. The Hi-Vol sampler should be at a height of 2 to 15 m.

The sampler should be located well away from obstructions; in general, the distance between the sampler and the nearest large obstruction should be about twice the height of the obstruction. Unless the sampler is supposed to collect large particles that might be typical of the neighborhood, the sampler should be located in an area with a ground cover that will minimize the incidence of blowing dust. If samples are to be collected that represent the full size range, then the site selected should be surrounded by a surface that is typical of the neighborhood as a whole. If the surrounding area is paved, and the emphasis is on small particles, then it should be cleaned often enough to prevent the settled large particles from biasing the TSP samples. In any event, the area directly beneath the Hi-Vol sampler should be such that the exhausted air from the sampler itself does not raise spurious dust. Figure 21 shows a TSP sampler located in a small park within a residential neighborhood.

Some auxiliary measurements, such as wind speed and direction, are desirable for a neighborhood station. The anemometer should be placed about 10 m above the general level of the surroundings; it should be well away from any structures of comparable height. Traffic counts on nearby streets and the wind measurements could both provide valuable information for the interpretation of the measured TSP concentrations. For example, the causes of anomalously high values might be identified with unusual traffic conditions or with entrained dust during periods of high wind.

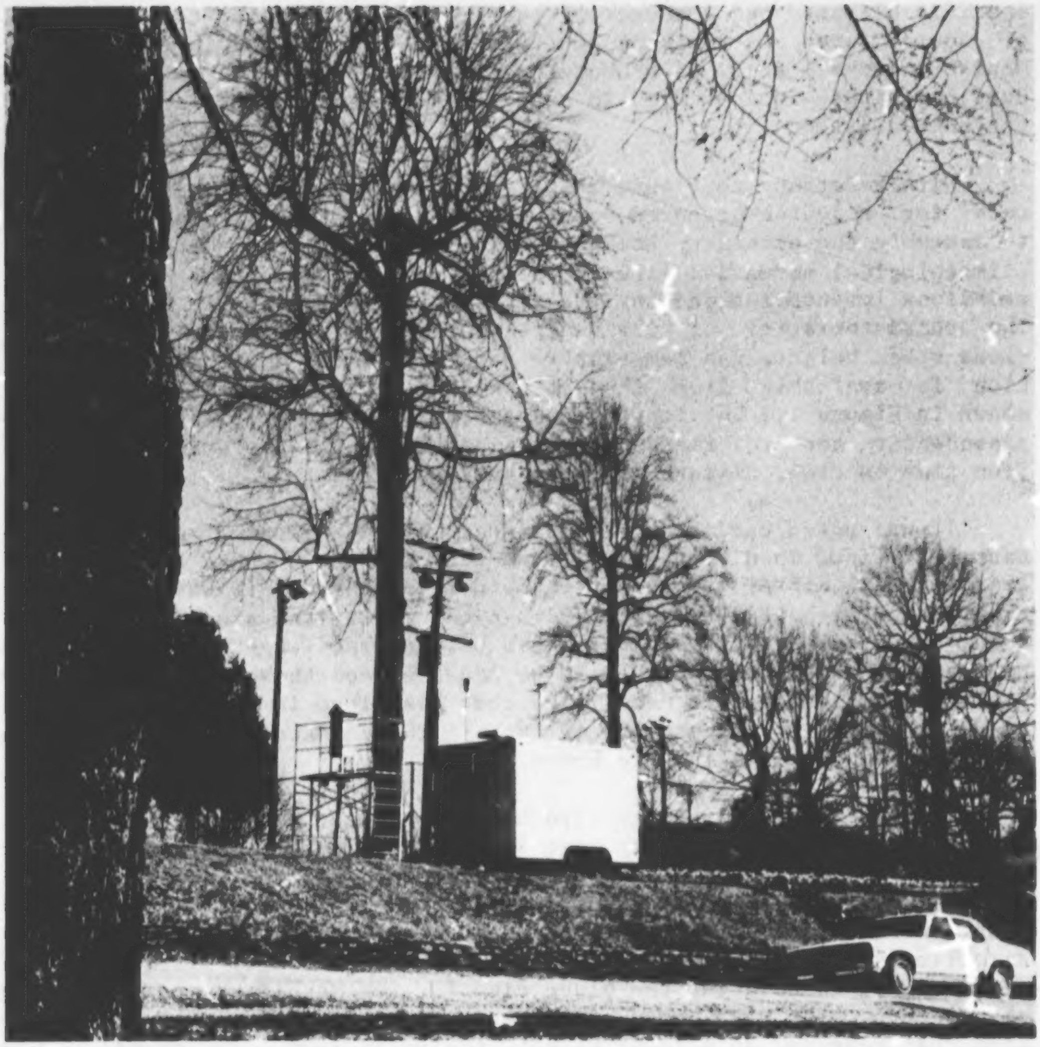


FIGURE 21 HIGH VOLUME SAMPLER LOCATION IN RESIDENTIAL NEIGHBORHOOD PARK

C. Source Oriented Stations

Figure 22 is a schematic diagram of a procedure for locating a monitoring site that will provide information about the effects of a specific elevated point source of particulates. We refer to this type of source when we speak of source-oriented monitoring in this report. Monitoring the effects of ground-level sources--highways and fugitive dust emissions--is addressed in connection with middle-scale stations in the next section.

With reference to Figure 22, it shows that the site selection process for a source-oriented monitor begins with the familiar admonition to assemble the necessary background information; in this case, it is climatological summaries like the STAR program output, maps of the area, emissions inventories and the characteristics of the source of interest. The characteristics of the source that are of particular interest include stack height, gas temperature and flow rates. Most such information is available from the National Emissions Data System (NEDS), as shown in Figure 11, but it might be useful to verify these facts independently and to find out the extent to which the emissions might, from time to time, deviate from the average values.

It was noted earlier that the impact of an elevated point source can be defined in different ways and that the areas where the impact is greatest will differ according to the definition that is used. In general, the highest short-term average concentrations are most likely to occur nearer the stack than the areas of greatest long-term average concentration. A decision has to be made between these two kinds of impact. A simple computer model like that described in Appendix A can be used to identify either kind of area if the climatological factors and the stack characteristics are known.

Reasonable estimates can also be made without the computer. The maximum long-term impact is most likely to be associated with the most frequent combination of wind direction, speed, and stability, as determined from the STAR program output. Obviously, if this is the case the downwind direction for the most frequent combination is the most likely direction for maximum long-term impact. The most likely distance can be estimated by calculating the plume rise for the stability and wind speed of concern. The wind speed at the top of the stack is likely to differ from that measured at a lower height, typically 10 m. The speed should be corrected to stack height; Beals (1971) gives information for such corrections, and they are summarized in Figure A-2 of Appendix A. Briggs (1973) gives equations for the determination of plume rise. Once the height of the plume is known for these conditions, then the distance to the maximum concentrations for that case can be estimated from graphs given by Turner (1969). Figures 23 and 24 show two of these graphs. The ordinate in these graphs is a concentration normalized for emission rate, Q, and wind speed, u.

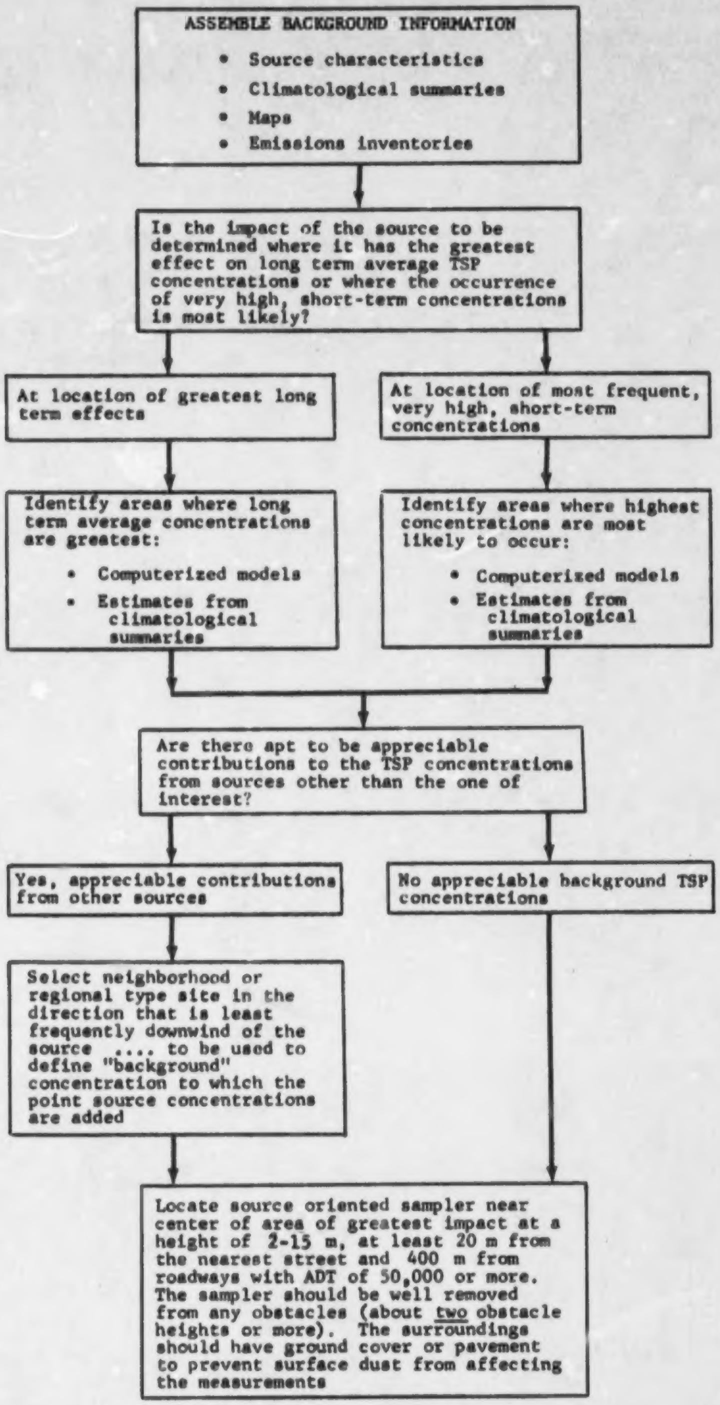
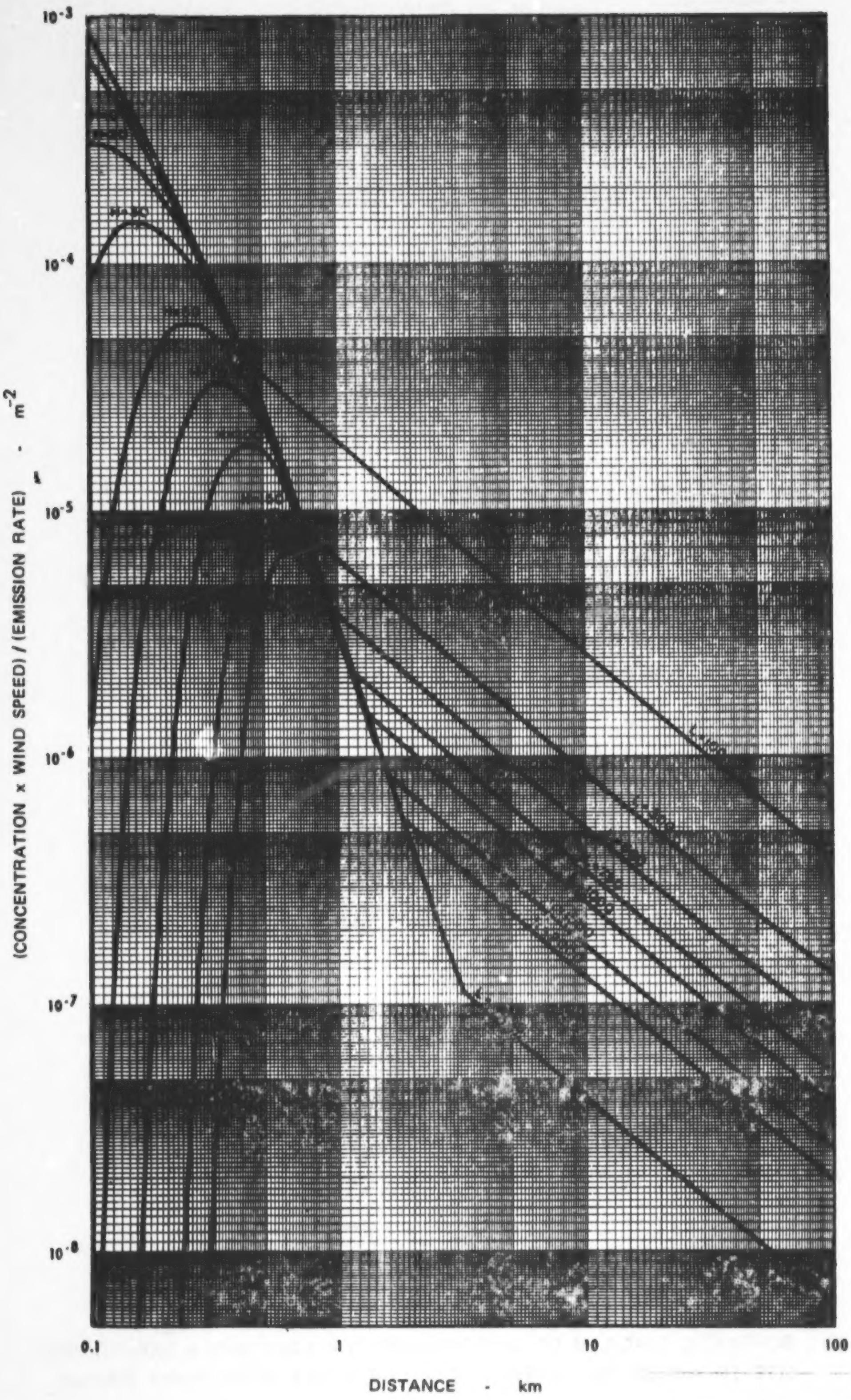

ASSEMBLE BACKGROUND INFORMATION
• Source characteristics
• Climatological summaries
• Maps
• Emissions inventories
Is the impact of the source to be determined where it has the greatest effect on long term average TSP concentrations or where the occurrence of very high, short-term concentrations is most likely?
At location of greatest long term effects
At location of most frequent, very high, short-term concentrations
Identify areas where long term average concentrations are greatest:
• Computerized models
• Estimates from climatological summaries
Identify areas where highest concentrations are most likely to occur:
• Computerized models
• Estimates from climatological summaries
Are there apt to be appreciable contributions to the TSP concentrations from sources other than the one of interest?
Yes, appreciable contributions from other sources
No appreciable background TSP concentrations
Select neighborhood or regional type site in the direction that is least frequently downwind of the source .... to be used to define "background" concentration to which the point source concentrations are added
Locate source oriented sampler near center of area of greatest impact at a height of 2-15 m, at least 20 m from the nearest street and 400 m from roadways with ADT of 50,000 or more. The sampler should be well removed from any obstacles (about two obstacle heights or more). The surroundings should have ground cover or pavement to prevent surface dust from affecting the measurements

FIGURE 22 SCHEMATIC DIAGRAM OF A PROCEDURE FOR LOCATING A MONITORING SITE TO ASSESS THE EFFECTS OF A LARGE, ELEVATED POINT SOURCE



Source: Turner, 1969

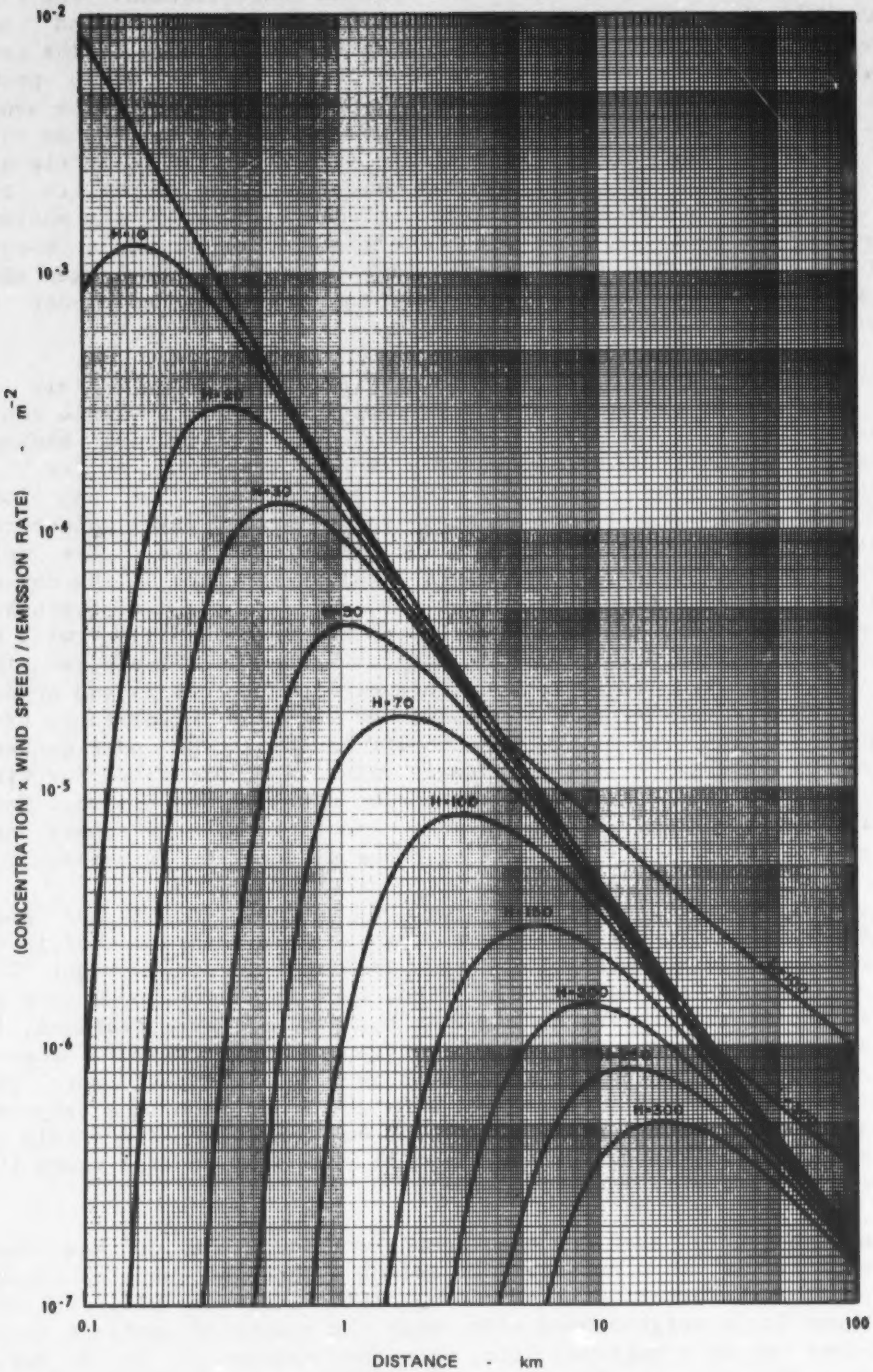
FIGURE 23 NORMALIZED GROUND-LEVEL CONCENTRATION UNDER EXTREMELY UNSTABLE CONDITIONS

The actual ground level concentration is of less importance to the siting problem than the location of the maximum concentration. The figures show that the concentration rises rapidly to a maximum and then falls more gradually as distance from the source increases. If the particles are small so that their fall is negligible, then it would probably be wise to locate the sampler slightly beyond the maximum to avoid the possibility of being too close and hence finding concentrations that are much too low. Particles of appreciable size will tend to settle and thereby move the location of the maximum concentrations closer to the stack. In such instances, sampling at the location of the maximum predicted for the negligible settling case would still provide a margin for error. It would also tend to bias sampling against the larger particles, which will tend to reach their maximum concentrations closer to the source.

Although the highest short-term concentrations are most likely at ground level under extremely unstable conditions, these unstable condtions can only persist for a few hours a day, during periods of maximum insolation. The short-term NAAQS specify 24-hour averaging, so for this type of monitoring those conditions that can persist for day long periods and still lead to the reasonably high ground level concentrations provide the best guidelines for the siting procedure. The only atmospheric stability class that can occur at any time of the day or night is the neutral category (Pasquill, 1961). The wind directions and wind speeds occurring most frequently with neutral stability will be available from the output of the STAR program. The effective plume rise should be calculated for the most frequent wind directions and speeds and then Figure 24 can be used as a basis for locating the distance from the source to the region of maximum TSP concentration under neutral conditions--remembering that the ordinate values are normalized for wind speed. The direction to the best monitoring site will be the most frequent direction occurring during neutral conditions. If there are several common directions, then more than one site may be necessary.

Figure 22 shows that after an area of maximum impact has been identified--whether it is short-term or long-term impact that is of interest--then it is necessary to check to see if other major TSP sources impact on the same area. If so, then it will be necessary to provide an additional station to measure "background" concentrations. In this case, a background concentration is supposed to represent the concentration that would prevail if the source of interest were not present. Such a site would usually be a neighborhood site in a city, or a regional site in a rural area. It should be as similar as possible to the source-oriented site, except that it should be located where the source will influence it least frequently.

After the general area for the source-oriented monitor has been identified, it is then necessary to select a specific location within that area. The characteristics of the specific location will be the same as those for a neighborhood site, when the source of interest is in an urban area, or as a regional site, when the source is in a rural area. A high-volume sampler between 2 to 15 m in height, well removed from roadways, fugitive dust sources, and obstacles to air flow is desirable.



Source: Turner, 1969

FIGURE 24 NORMALIZED GROUND-LEVEL CONCENTRATION UNDER NEUTRAL CONDITIONS

Measurements of wind speed and direction at the sampling site or near the source of interest would be extremely valuable. Such measurements would be invaluable for the interpretation of the collected TSP data. The wind speed and direction can be used to determine whether the site was actually exposed to the maximum impact of the source. Fluctuations in wind direction can also be used to estimate atmospheric stability. If available, records of the operating conditions at the source would also be very valuable as a supplement to the TSP data.

D. Middle-Scale Stations

1. General

As noted earlier, there are different types of monitoring sites that might be considered for measuring middle-scale TSP concentrations. These are those special sites that characterize conditions in a street canyon or along other types of roadway and traffic corridors. There are also needs for special sites to characterize the effects of small area sources. Although this section provides procedures for selecting special sites in street canyons and along traffic corridors, and provides guidelines for locating monitors that will determine concentrations around the small area sources, it should be recognized that such sites have rather uncertain application in routine monitoring. In general, the concentrations measured at such sites will not be representative of typical population exposures over the 24-hour averaging period specified as part of the NAAQS for TSP. Nevertheless, it will sometimes be desirable to monitor concentrations in such areas.

2. Special Roadway Sites

Figure 25 provides a schematic diagram of the procedure for locating a TSP monitor in a street canyon. As with the selection of other types of sites, the first step of the procedure is to acquire the necessary background information. This includes the average daily traffic on all the streets in the area, wind roses, and maps showing street widths, and building heights. These can be obtained from land use maps or by having personnel survey the area and estimate a typical height for each side of each block. Emissions inventories will also be required, especially those identifying the location and magnitude of important nearby point sources. An emissions inventory of distributed source emissions would be desirable, but in lieu of that, some surrogate such as employment, office and retail space, or population may be used to estimate emissions from space heating.

As indicated in Figure 25, this type of station may have one of two basic, special monitoring objectives. One might be to typify the worst possible conditions to which the city's street canyons might be exposed, and the second is to typify more nearly average conditions throughout a downtown area. If the highest concentrations are to be monitored, then the next step is to identify the areas of greatest emissions. The streets with greatest traffic should be identified because

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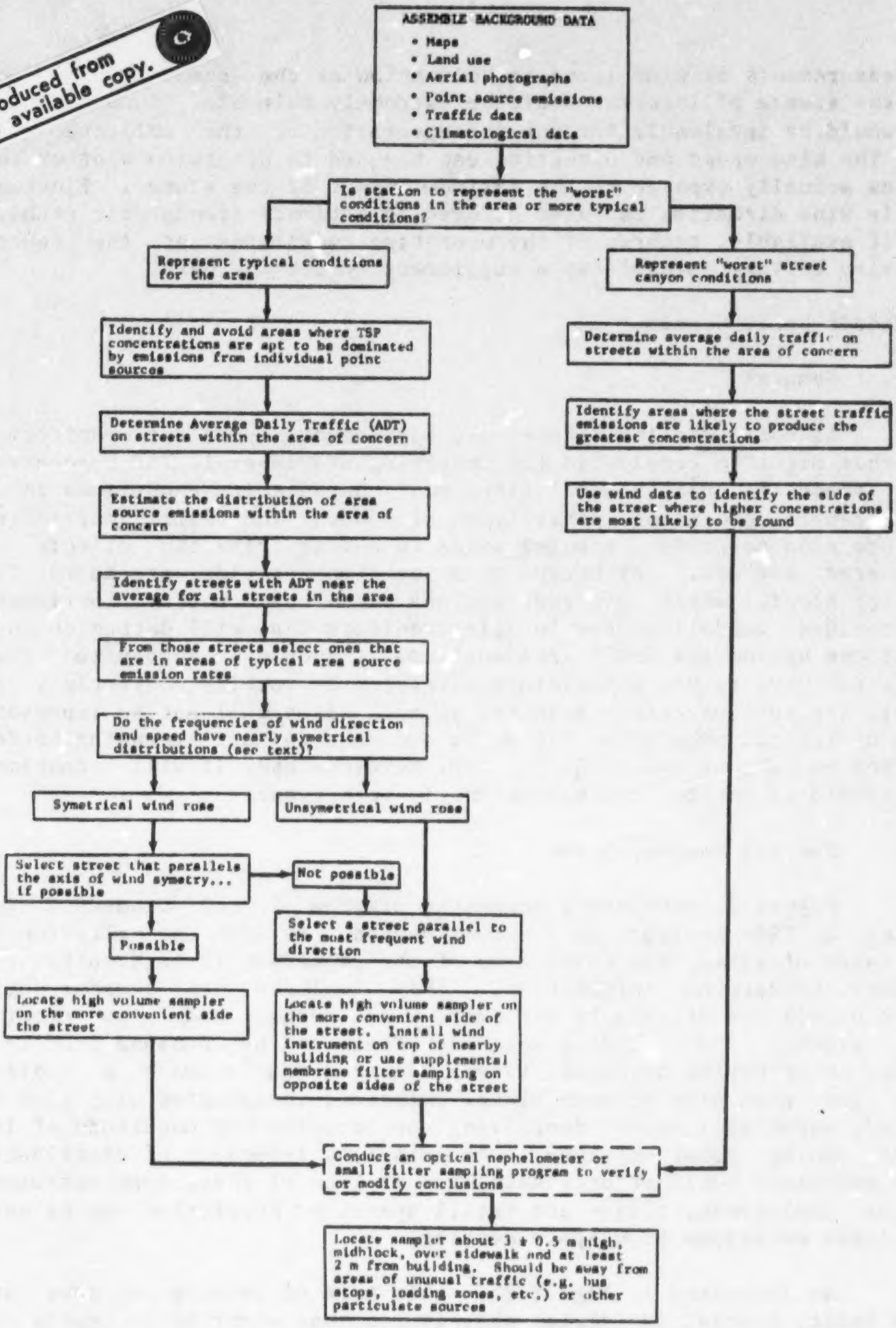
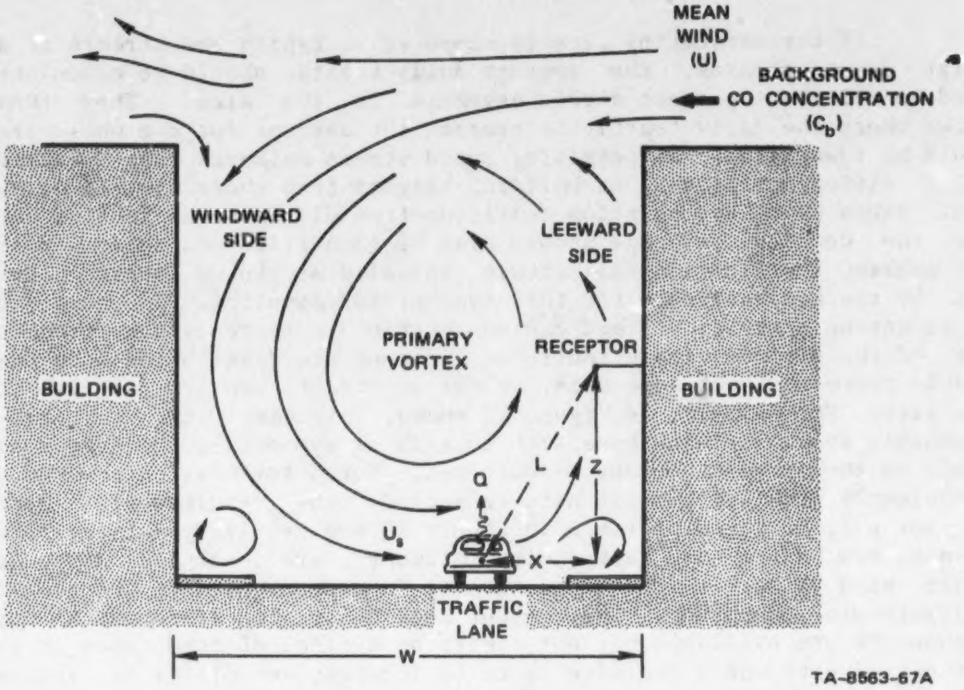

ASSEMBLE BACKGROUND DATA
• Maps
• Land use
• Aerial photographs
• Point source emissions
• Traffic data
• Climatological data
Is station to represent the "worst" conditions in the area or more typical conditions?
Represent typical conditions for the area
Represent "worst" street canyon conditions
Identify and avoid areas where TSP concentrations are apt to be dominated by emissions from individual point sources
Determine average daily traffic on streets within the area of concern
Determine Average Daily Traffic (ADT) on streets within the area of concern
Identify areas where the street traffic emissions are likely to produce the greatest concentrations
Estimate the distribution of area source emissions within the area of concern
Use wind data to identify the side of the street where higher concentrations are most likely to be found
Identify streets with ADT near the average for all streets in the area
From those streets select ones that are in areas of typical area source emission rates
Do the frequencies of wind direction and speed have nearly symetrical distributions (see text)?
Symetrical wind rose
Unsymetrical wind rose
Select street that parallels the axis of wind symetry... if possible
Not possible
Select a street parallel to the most frequent wind direction
Possible
Locate high volume sampler on the more convenient side the street
Locate high volume sampler on the more convenient side of the street. Install wind instrument on top of nearby building or use supplemental membrane filter sampling on opposite sides of the street
Conduct an optical nephelometer or small filter sampling program to verify or modify conclusions
Locate sampler about 3 ± 0.5 m high, midblock, over sidewalk and at least 2 m from building. Should be away from areas of unusual traffic (e.g. bus stops, loading zones, etc.) or other particulate sources

FIGURE 25 SCHEMATIC DIAGRAM OF A PROCEDURE FOR LOCATING SPECIAL SITES IN STREET CANYONS



SOURCE: Johnson et al., 1971

FIGURE 26 SCHEMATIC DIAGRAM OF AIR CIRCULATION WITHIN A STREET CANYON

the dust generated by traffic is produced near ground level and the public will therefore be exposed to its effects before it has been diluted by turbulent mixing. Draftz (1975) has confirmed that street dust and vehicular emissions are dominant in samples collected near streets.

Air circulations within the street canyon will cause gradients in the concentration of pollutants emitted at street level, when the wind at roof level is blowing across the street. Figure 26, from Johnson et al. (1971), shows the circulation within the typical street canyon for a cross-street wind at roof level. In the figure, the wind blowing from right to left at roof level causes street level air movement in the opposite direction so that traffic dust is swept to the right side of the street, the side from which the roof level wind is blowing; this will cause higher TSP concentrations to be observed on that side. Furthermore, upward air motions will keep the larger particles suspended longer than on the side with the downdrafts. These facts must be taken into account when locating street monitors. For a site to monitor the highest concentrations, the preferable sampler location is on a street more or less perpendicular to the most frequent wind direction for times of strong wind, and on the side of the street from which those winds blow.

If the monitoring site is supposed to typify the streets of an entire downtown area, the average daily traffic should be calculated based on all the important street segments in the area. Then those blocks where the daily traffic is nearest the average for the whole area should be identified. If possible, avoid street segments that have radically different widths or building heights from those typical of the area. Areas where the emission densities from distributed sources are near the downtown average should also be identified and those streets with average traffic that fall within typical distributed source areas will be the most suitable for this type of TSP sampling. The next step for selecting a typical street canyon location is to study the frequencies of the various wind directions. If they are distributed with reasonable symmetry about some axis, select a street nearly parallel to that axis. For example, as Figure 10 shows, Salt Lake City, Utah, has a reasonably symmetric wind rose with an axis of symmetry running approximately north-northwest to south-southeast. North-south streets would be sufficiently parallel to this axis to satisfy the requirement. Most, but not all, of the wind roses in Figure 10 are nearly symmetric; Albuquerque, New Mexico, and Kansas City, Missouri, are examples of asymmetric wind roses. A word of caution is in order regarding the usually available wind summaries. The Weather Service station for which wind frequencies are available may not always be typical of conditions in the part of the city where the site is to be located, especially in regions with complex topography. Therefore, it will often be wise to seek advice from local meteorologists and make adjustments where necessary.

When the site is to provide a measure of typical TSP concentrations, then it should be located so that the effects of cross-street concentration gradients discussed earlier will be minimized. This is different from the case where the site is supposed to measure worst-case concentrations and an attempt is made to locate the sampler on the side with highest values. To minimize the effects of the gradients, it is desirable to have a street where the wind blows with equal frequency from the opposite sides of the street; that is, the street should be aligned with the axis of symmetry of the wind rose. In such a case, the side of the street on which the inlet is located is not of much importance. If the wind rose is not symmetric or no typical street parallel to the axis of symmetry can be found, then the next best choice is a street parallel to the most frequently occurring wind direction. In the latter case, it may be desirable to augment the regular high-volume sampling with other measurements taken on opposite sides of the street and with roof level wind measurements. These supplemental data can be used to estimate the extent to which the samples collected at the regular sampling location are atypical of the average within the street canyon. A limited sampling program using smaller filters or nephelometers can provide information about whether the tentatively selected locations are indeed representative of conditions in the downtown area. Such a program could also be used to find other representative locations that might be more convenient for one reason or another; for example, space might be more readily available and less expensive, security might be better, and so forth.

If the special monitoring purpose is to characterize public exposure, the location of the Hi-Vol sampler should be near the breathing zone, say at a height between 2 and 15 m over the sidewalk, but not closer than about 2 m to the buildings. It should not be closer than 10 meters to a cross street. Several days should be spent observing activity around any tentatively selected location to make sure that vehicles do not commonly stop and spend extended periods of time idling or that other unexpected dust sources are not present. Bus stops, loading zones, and areas where lines of cars form regularly should be avoided. If the purpose were to measure vertical gradients then a variety of heights would be used.

A vehicle counter would be a valuable instrument to use in conjunction with the TSP monitor. Its records could be used to identify unusually heavy traffic conditions. Wind measurements at roof level might be used for measuring general air flow to evaluate the street canyon air circulations and their possible effects on the observations. Identification of periods with strong winds that might increase blowing street dust would be very useful to data interpretation.

Figure 27 schematically illustrates a procedure for selecting high-volume sampler locations to characterize conditions near roadways. Many similarities exist between this procedure and that suggested for locating street canyon sites (Figure 25). Both procedures begin, as should all site selection, with the acquisition of background information, e.g., traffic data, street maps, emissions inventories, and climatological information. A decision must also be made whether the purpose of the monitor is to determine the highest particulate concentrations in the vicinity of roadways or to monitor more typical conditions. In both cases, atypical locations dominated by large point source emissions should be avoided, especially when the desire is to characterize roadway sources.

If the monitor is to measure high TSP concentrations arising from traffic, then it will be necessary to identify the areas of greatest daily traffic volumes. As with the street canyons, road segments with the greatest traffic should provide suitable locations for sampling TSP concentrations that are characteristic of the highest concentrations generated on the particular type of roadway being considered. The most appropriate side of the roadway for such monitoring is that side which is most frequently downwind.

If the monitor is supposed to characterize concentrations typical of those found near many roadways in the area, then average traffic will be sought. The roadway should parallel the axis of symmetry of the wind rose, if possible. (The concept of symmetry of wind roses was discussed in connection with the selection of street canyon sites.) If it does, then the sampler can be placed on either side of the roadway. The basis of selecting one side over the other might then be convenience, or greater population exposure. If the wind rose is not symmetric then a roadway parallel to the most frequently occurring wind direction should be chosen. Again, the choice of the side of the road is arbitrary.

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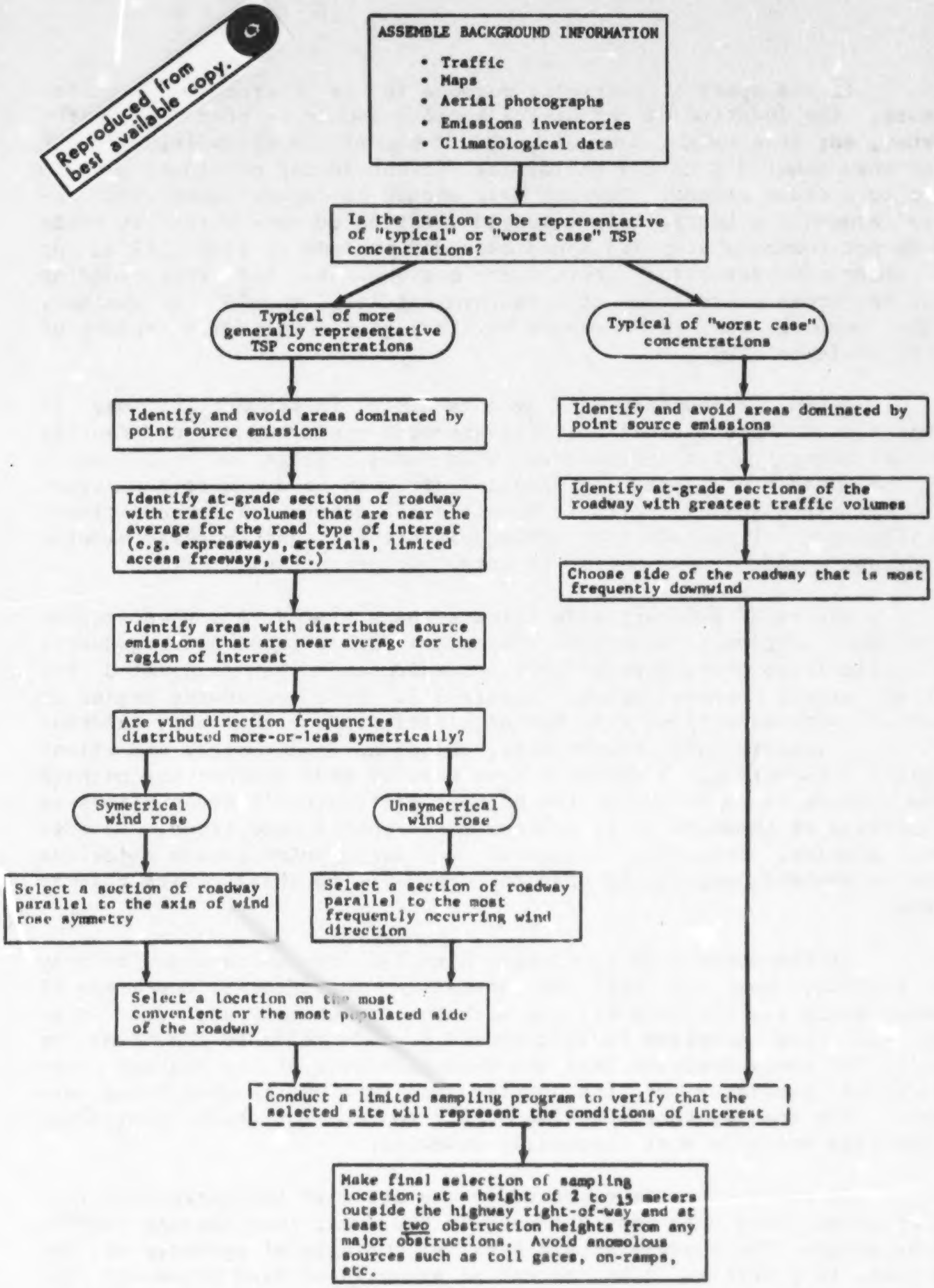

ASSEMBLE BACKGROUND INFORMATION
• Traffic
• Maps
• Aerial photographs
• Emissions inventories
• Climatological data
Is the station to be representative of "typical" or "worst case" TSP concentrations?
Typical of more generally representative TSP concentrations
Typical of "worst case" concentrations
Identify and avoid areas dominated by point source emissions
Identify and avoid areas dominated by point source emissions
Identify at-grade sections of roadway with traffic volumes that are near the average for the road type of interest (e.g. expressways, arterials, limited access freeways, etc.)
Identify at-grade sections of the roadway with greatest traffic volumes
Choose side of the roadway that is most frequently downwind
Identify areas with distributed source emissions that are near average for the region of interest
Are wind direction frequencies distributed more-or-less symetrically?
Symetrical wind rose
Unsymetrical wind rose
Select a section of roadway parallel to the axis of wind rose symmetry
Select a section of roadway parallel to the most frequently occurring wind direction
Select a location on the most convenient or the most populated side of the roadway
Conduct a limited sampling program to verify that the selected site will represent the conditions of interest
Make final selection of sampling location; at a height of 2 to 15 meters outside the highway right-of-way and at least two obstruction heights from any major obstructions. Avoid anomolous sources such as toll gates, on-ramps, etc.

FIGURE 27 SCHEMATIC DIAGRAM OF A PROCEDURE FOR LOCATING SPECIAL SITES NEAR TRAFFIC CORRIDORS

If it is not possible to locate appropriately aligned roadways, then a brief supplemental measurement program, collecting samples at several locations, or using nephelometry to identify areas of large spatial gradient, would be very useful to establish the representativity of a selected location, or at least, the relationships among measurements from the selected location and other sites. Such a supplemental measurement program would be useful in any case, but particularly so in those instances where something less than ideal sites have to be used.

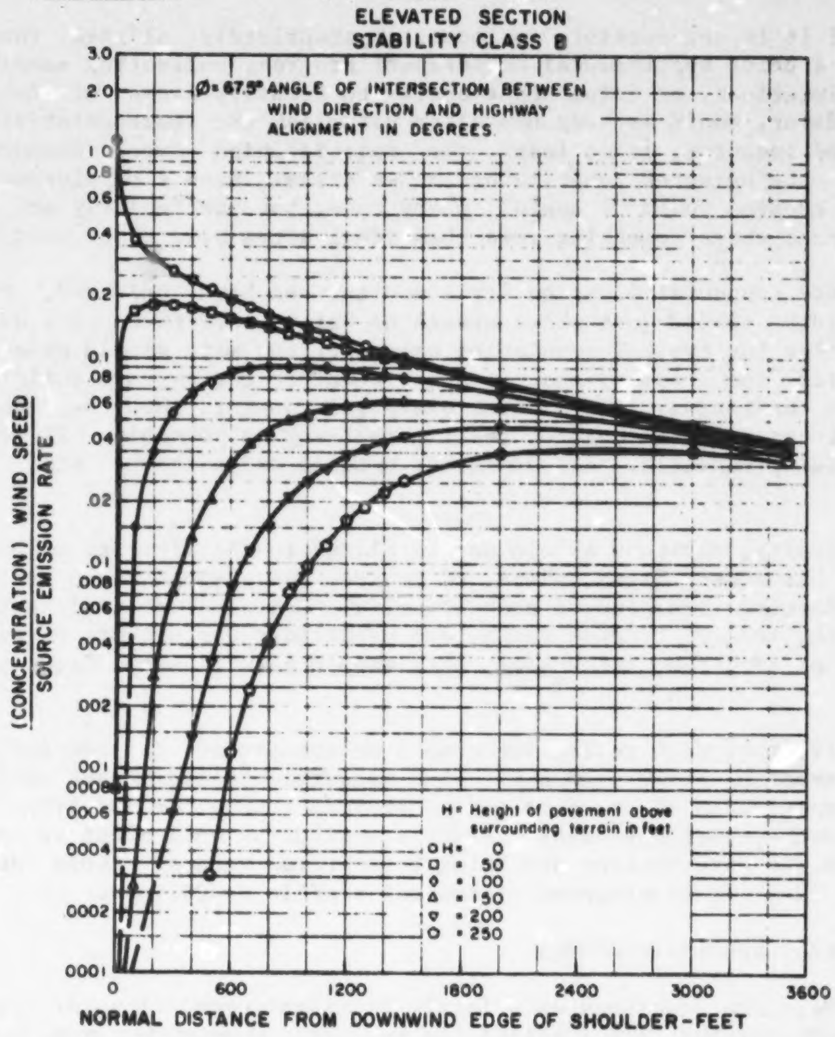
Once a general location for a monitor has been selected, the inlet should be placed just above breathing height. If there is a need to characterize the typical population exposure, the site should be at a distance from the roadway that is about equal to the average building setback from the roadway. If a worst example is sought, then the monitor should be as near the edge of the right-of-way as possible. If gradients are being measured, then different heights and setbacks will be used.

Finally, monitors should not be placed in the vicinity of possibly anomalous source areas unless, of course, the purpose is to evaluate their effects. Examples of such anomalous areas include toll gates on turnpikes, metered freeway ramps, and drawbridge approaches. As with other types of sampling, the roadway site should be well away from obstructions.

Corollary data collection should be considered in connection with TSP sampling along roadways. Wind measurements are always useful to the interpretation of the data and to provide inputs for modeling or other research-oriented studies. Traffic monitoring will often be useful when the TSP observations are being interpreted because those data can help to identify occurrences of unusual traffic conditions.

3. Other Special Problems

There are occasions when fairly detailed descriptions of pollutant concentrations are required for the area surrounding some special kind of source. Such sources include paved and unpaved roadways, aggregate storage piles, and activities such as farming and heavy construction. For longer-term, routine monitoring near such sources, the same principles will apply as in the sampling site selection methods that have already been given. The sites will be located downwind for the most frequently occurring wind direction. If maximum concentrations are required, the sampler will be located at the closest publicly accessible sites when the source is at ground level. For elevated sources, such as roadways, the maximum concentrations will occur farther away. Beaton et al. (1972) have prepared a number of graphs relating ground level concentrations to roadway configurations and meteorological conditions; Figure 28 shows an example of these graphs. Such graphs would be useful for locating high-volume samplers in the most likely places for finding maximum concentrations of small particles. The maximum concentrations of larger particles with appreciable settling velocities will be found closer to an elevated source than indicated by calcuations that have assumed negligible settling.



SOURCE: Beaton et al, 1972

FIGURE 28 NORMALIZED GROUND LEVEL CONCENTRATION FROM AN ELEVATED ROADWAY

If the objective of the monitoring is to evaluate TSP emissions from fugitive dust sources, then special monitoring will be required. It is beyond the scope of this report to describe such sampling methods. Lawrence Berkeley Laboratory (LBL, 1975) has prepared a comprehensive review of particulate sampling methods and equipment that contains much valuable information. Cowherd and his associates at Midwest Research Institute have developed methodologies for evaluating fugitive source emissions (see e.g., Cowherd et al., 1974) that might have application to other TSP-sampling objectives.

V RATIONALE FOR SITE SELECTION CRITERIA

A. Background

The site selection procedures in the preceding section of this report contain some very specific recommendations concerning such things as the heights of inlets and distance between monitors and TSP sources. The recommendations have been derived through a variety of methods. In most cases, an a priori judgment is required at some point, but an attempt has been made to make those a priori judgments as recognizable and consistent as possible. This section presents the reasoning and judgments that were used to arrive at the recommendations.

In some cases, such as the recommended heights of the sampler, the choices are straightforward. The importance of population exposure to TSP concentrations demands sampling near average breathing heights. Practical factors, like prevention of vandalism and possible obstruction to pedestrians, require that the sampling be elevated; the recommended 2 meters is an admittedly a priori compromise between these two requirements. Practical considerations will almost always prevent the sampler from being located at exactly a 3-m height, so an acceptable range of heights had to be specified. If we can translate this range of heights into some corresponding measure of the expected variability of concentrations over that height interval, then it will be much easier to decide if the results are acceptably close to those that would be observed at the "standard" 3 m height.

Similarly, the recommended spacing between neighborhood or regional sites and specific sources can be more clearly understood if it is restated in terms of the expected maximum contributions of the source to the measured TSP concentrations at the site. Acceptable levels of interference by a specific source can be defined, and then the minimum spacing between the source and the monitoring site can be determined so that level is not likely to be exceeded.

B. Sampler Locations

1. Background

It has been recommended that most sampling should be done at a height between 2 and 15 m. The choice of 2 m for the minimum height has already been explained. It is a compromise between the representation of breathing height and the prevention of vandalism, and it is consistent with recommendations made for the monitoring of other pollutants.

The recommended range of heights is also a compromise to some extent. For consistency and comparability, it would be desirable to have all inlets at exactly the same height, but practical considerations will often prevent this. Therefore, some reasonable range must be specified, and 13 m should provide adequate leeway to meet most requirements.

Record (1976) has examined annual mean TSP concentrations from several stations and found that the amount of the average TSP concentration attributable to a nearby roadway is approximately proportional to the reciprocal of the distance of the sampler from the roadway, i.e.,

$$C = k\,T/r$$

where C = average contribution of paved road to measured TSP--$\mu g\ m^{-3}$

T = average daily traffic--vehicles day^{-1}

r = slant distance between monitor and roadway--m

k = proportionality constant = $0.046\ \mu g\ day\ m^{-2}\ veh^{-1}$

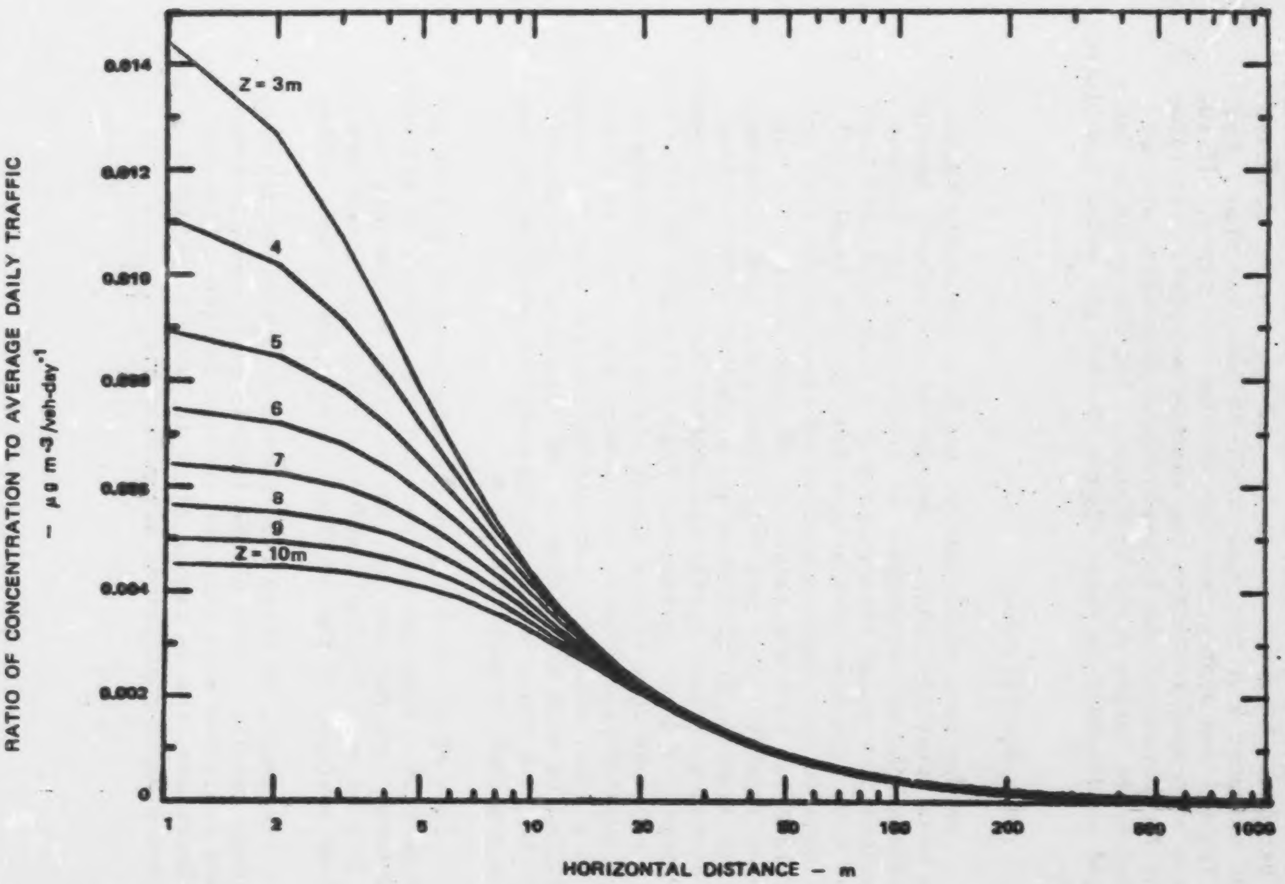
Converting units and making trigonometric substitutions gives:

$$C/T = 0.046/\sqrt{z^2 + x^2}$$

where height, z, and horizontal separation, x, are in meters. The equation will estimate the impact of nearby streets, or more importantly, the distances at which those impacts will be at acceptable levels. It can also be used to estimate the impact of changing the height of the sampler. The expression given above gives equal weight to the effects of vertical and horizontal separation between the sampler and the source, when in fact the vertical effects are probably more pronounced. Thus, application of the expression to the effects of changing sampler height is likely to underestimate the effects somewhat.

Figure 29 shows how the average contribution of a roadway varies with traffic, and with the vertical and horizontal separation between the road and the sampler, according to the equation given above. It has been noted by Record (1976) that there is a tendency to overestimate at the higher concentrations. This implies that the introduction of roadway dust into the air is less than proportional to the traffic volume, but data for very high traffic volumes have not been included among the data from which the equation was derived.

An overestimate is not very important to this application which focuses on keeping contributions from an individual roadway low. How low the contribution should be is one of those arbitrary decisions that is necessary. It seems that a reasonable limit might be ten percent of the federal standard, or about 7.5 $\mu g\ m^{-3}$, for urban stations. For regional stations, the maximum allowable contribution from an individual source might be five percent of the secondary standard--3 $\mu g\ m^{-3}$.



SOURCE: Record (1976)

FIGURE 29 TSP CONTRIBUTION FROM ROADWAYS ACCORDING TO RECORD'S EMPIRICAL RELATIONSHIP

2. Separation from Paved Roads

a. Horizontal

With the criteria described above it is possible to use the equation, or Figure 29, to obtain estimates of the minimum acceptable separation between a high volume sampler and the nearest roadway. Assuming a height of about 4 m for the high-volume sampler, the values given in Table 5 are appropriate for various road types. If the criteria that have been used to define the maximum acceptable contributions, i.e., 5 or 10 percent of the federal annual standards, are not satisfactory, then other values could be chosen. The distances in Table 5 could be changed accordingly by using Figure 29 with the value considered more appropriate.

b. Vertical Placement

As has been noted before, the most desirable height for a monitor is near breathing height. Because of the general impracticality of placing a high volume sampler at breathing height in many locations, the height of 2 m has been adopted as a most desirable compromise. How far from this most desirable height can the sampler be placed and still provide measurements similar to those at the standard heights? Figure 29 shows that the height of the sampler is not a very important factor at locations that are sufficiently far from a roadway source; the various sampling heights show quite similar contributions. However, as the distance between source and monitor declines, the importance of the vertical placement increases. Figure 29 makes it clear that if the sampler is at least 20 m from a street, tradeoffs are possible and there will be considerable freedom in choosing the height at which the sampler can be placed, while still remaining certain that the measurements will not differ by much from those at the "standard" 2-m height. Anywhere in the 2 to 15 m range should provide similar results, as long as the sampler is set back by more than 20 m.

Pace et al. (1977) have obtained results similar to those shown in Figure 29. They did not consider the effects of horizontal separation between site and sources, but did find strong vertical gradients up to 10 m or so. The implications are that the sites must be well separated from sources, if the vertical effects are to be avoided.

It should be noted that Record's expression applies to long-term average results. Some of the individual 24-hour averages are likely to have exhibited more than the average influence from the local sources. Therefore, the distances cited in Table 5 should be taken as minima and greater separations are preferable.

Table 5

MINIMUM SEPARATIONS BETWEEN A NEIGHBORHOOD AND REGIONAL SAMPLERS 4-METERS HIGH FOR DIFFERENT TYPES OF ROADWAY

Type of Roadway	Typical Daily Traffic Volume (vehicles day^{-1})	Minimum Distance to Sampler (meters) Neighborhood Site	Regional Site
Major arterial, expressway	20,000-50,000	125-300	300-750
Other arterial	2,000-20,000	15-125	30-300
Neighborhood street	< 2000	15	30

3. Separation from Unpaved Roads

It has been assumed that no unpaved roads will be near a neighborhood site, but this may not be so for regional sites that are located in rural areas. The presence of dirt roads in an area will raise TSP concentrations appreciably. Calculations based on line source equations and estimates of emissions from unpaved roads (Cowherd et al., 1974; Mann and Cowherd, 1975) indicate that samplers would have to be removed tens of kilometers from such roads if they have more than a hundred cars per day traffic to ensure that their contributions to TSP concentrations would be only a few $\mu g\ m^{-3}$. These results suggest that the effects of dirt roads can extend over very large areas and influence concentrations on the regional scale. Therefore it is not appropriate to try to place a regional TSP monitor so far from the unpaved roads that it does not reflect their contributions at all, but it should be placed where the gradients are small.

If the gradient arising from a specific source is expressed relative to the concentration arising from that source, it is independent of source strength. If a site is sufficiently far from a particulate source, then the gradient of concentration will not be affected appreciably by settling particles--all the large particles will have settled closer to the source. According to Mann and Cowherd (1975), particles with diameters larger than about 30 µm--and settling speeds greater than about 5 cm s^{-1}--will fall to the surface within about 100 m of the source. Thus, for greater distances the effects can be approximated by formulae that assume negligible settling. With this in mind, it is possible to use Ludwig and Kealoha's (1975) formulations. Using a value of

20 percent km^{-1} for the maximum acceptable gradient in the concentration arising from a specific source, they estimated that the minimum separation between sampler and line source should be about 4 km for neutral atmospheric stability. As noted earlier, neutral stability is the most commonly occurring condition and, the only stability class that could occur at any hour of a 24-hour TSP sampling interval.

4. Separation from Urban Regions

Our approach to defining the distance that a regional station should be outside of an urban area has been based on reasoning similar to that used above in connection with the determination of minimum separations between the sites and roadways. That is, an attempt has been made to limit the influence of the city on the nearby regional monitors. We have taken advantage of similar calculations made for other purposes. Figure 30 (from Stanford Research Institute, 1972) shows calculated relative concentrations downwind of a circular area , 70 km in diameter. Within the area, source emission rates are highest at the center, decreasing in Gaussian fashion to 24 percent of the central value at the edge. The figure shows that concentrations outside the city under the slightly unstable conditions that are frequent during the day are much lower than occur with the slightly stable conditions common at night. For purposes of calculation, we have assumed that the 24-hour averaging that is used for TSP sampling will result in concentrations somewhere between those shown in the two parts of the figure. A series of reports* indicates that although the emission rates do occasionally exceed 10 tons mi^{-2} day^{-1}, the areas where this occurs are limited. When the emissions are averaged over a larger part of the metropolitan area the emission rates are generally less than 1 ton mi^{-2} day^{-1}, or about 4 $\mu g\ m^{-2}\ s^{-1}$. If we choose to limit the urban impacts on regional stations to about 6 $\mu g\ m^{-3}$, and if we assume that minimum wind speeds averaged over the day are about 2 m s^{-1}, then Figure 30 can be used to estimate the minimum distances between the regional samplers and nearby cities. Summarizing,

Q = Emission rate = 4 $\mu g\ m^{-2}\ s^{-1}$
u = Wind speed = 2 m s^{-2}
X = Maximum acceptable concentration from city emissions = 3 $\mu g\ m^{-3}$
Xu/Q = Maximum acceptable normalized concentration = 1.5

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* published in 1968 and 1969 under the general title of "Report for Consultation on .... ", where the missing words name a U.S. city or region. Those regions considered were Baltimore, Boston, Buffalo, Cincinnati, Cleveland, Hartford, Kansas City, Los Angeles, Minneapolis, New York, Phoenix, Pittsburg, and Washington.

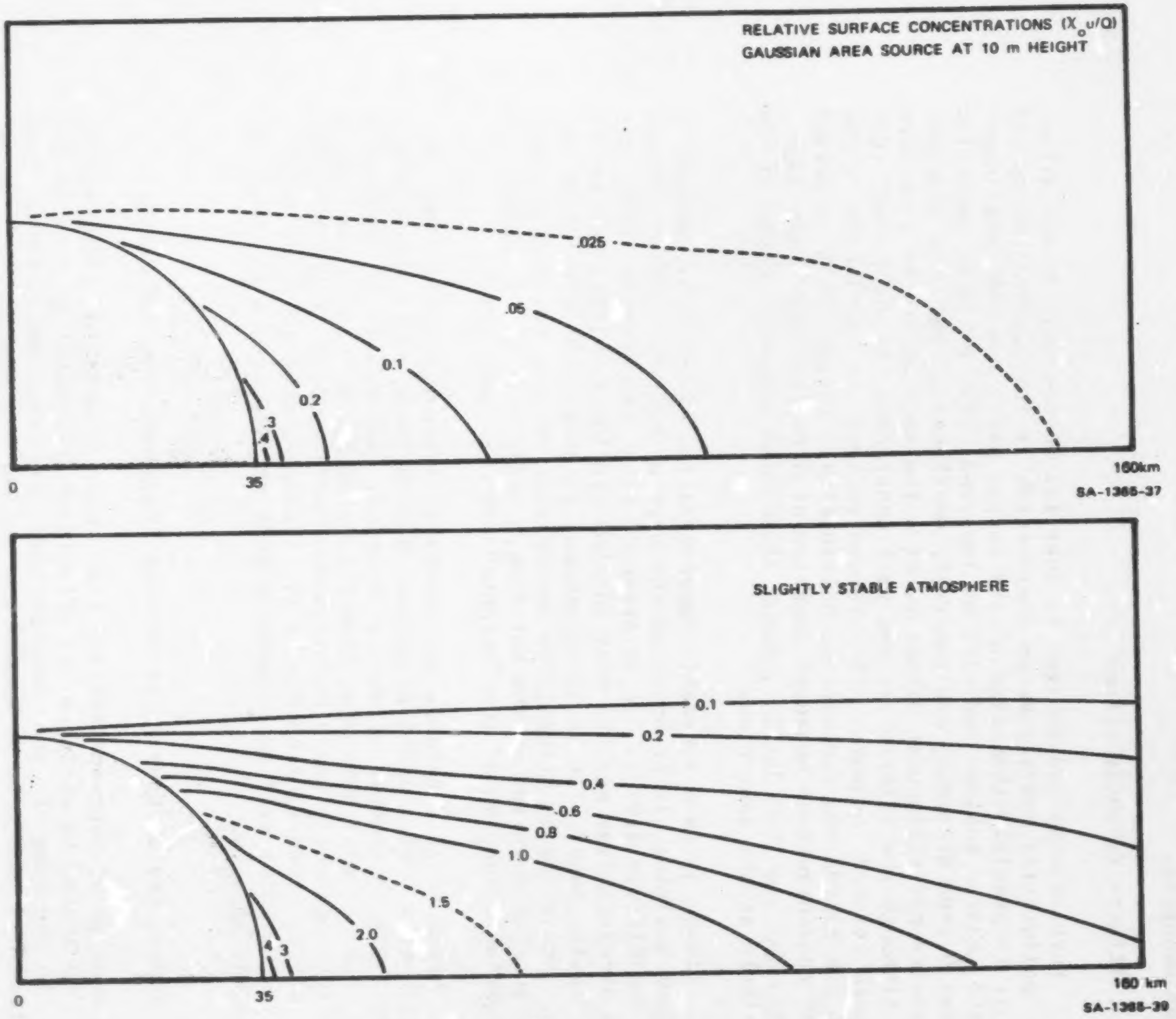

FIGURE 30 NORMALIZED CONCENTRATIONS DOWNWIND OF A CITY COMPUTED WITH A GAUSSIAN DISPERSION MODEL FOR TWO STABILITY CLASSES

Figure 30 shows that an average normalized concentration of less than 1.5 occurs at distances of only a few km from the city's edge. We have arbitrarily chosen 10 km, as a distance that should provide a reasonably conservative separation between sites and urban area sources. If other pollutants are to be measured along with TSP, then much larger separations will be required. For example, Ludwig and Kealoha (1975) have specified 35 km as the minimum separation for regional-scale monitoring of carbon monoxide.

5. Effects of Obstructions

Particulates are subject to inertial forces that do not affect gaseous pollutants; every time an obstruction is introduced into an air stream, it is possible that some of the larger particles will not negotiate the sharp angles and will be impacted. The smallest particles (less than 0.1-μm diameter) are generally unaffected, but the larger, more massive particles with diameters of a few microns can be lost more easily. Although the effects are not well understood, it does seem reasonable to expect measured TSP concentrations to be altered if the samplers are placed too close to an obstruction. Shelar (1974) observed that TSP concentrations measured downwind of a rooftop shed were significantly (at the 0.05 level) greater than those measured upwind of the same obstacle at the same time.

Figure 31 is a schematic representation of air flow around a sharp-edged building. It is based on the work of Halitsky (1961), Briggs (1973), and Gifford (1973). It is apparent from the figure that the greatest accelerations and the most complex airflow is within the region labeled "cavity zone". It would be prudent to avoid this area if at all possible. According to Briggs, the cavity zone extends to roughly 1-1/2 building heights downwind of the building. Using this as a guide, we have suggested a spacing of two "heights" from an obstruction.

Often it is desirable for practical reasons to place the Hi-Vol sampler on top of a small structure used to house other instruments. Figure 32 shows an example of such a location. Although it is desirable to have the sampler separated from the building, a location on top of the building apparently would not introduce serious bias if the building is not large. Judging from Figure 31, a sampler that is about 1-1/2 m above a 2 m building will be reasonably well removed from the worst of the turbulent effects.

C. The Importance of Sources at Various Distances from the Sampler

The concept of representativity has been translated into siting criteria by trying to minimize the effects of individual sources on the sampler. In the case of the neighborhood and regional sites, this minimization has been done by specifying how far the sampler must be removed from the sources. In essence, this approach emphasizes the lack of nearby sources. In the case of street canyon or traffic corridor sites, the nature of the adjacent source dominates the site selection process; the site is supposed to be located where the adjacent street and other surroundings are typical of the conditions that the data are supposed to represent. These approaches tacitly assume that the measurements will be disproportionately affected by nearby emissions. For a relatively inert gaseous pollutant whose sources are almost exclusively near ground level, the importance of nearby sources is well documented. Carbon monoxide is such a pollutant and several investigators (Ott, 1971; Kinosian and Simeroth, 1973; Perkins, 1973) have concluded that sources near the monitor have an influence on readings that is disproportionate to their strength.

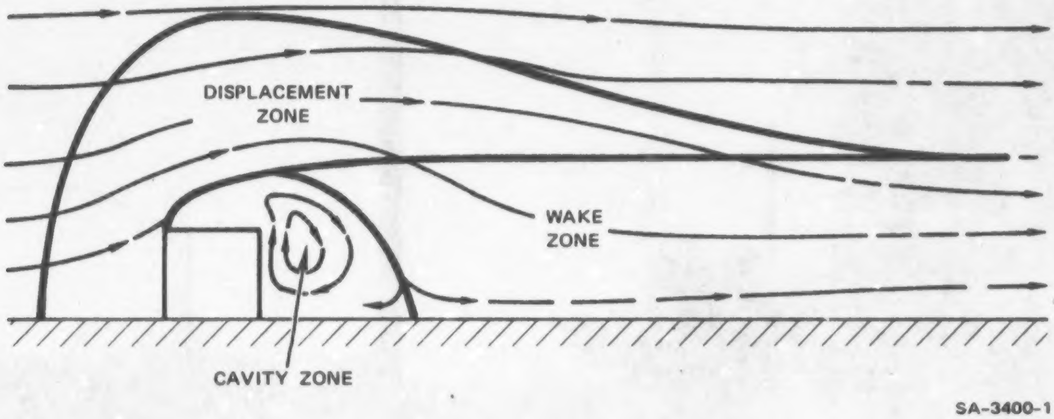

FIGURE 31 SCHEMATIC REPRESENTATION OF THE AIRFLOW AROUND AN OBSTACLE

Ludwig and Kealoha (1975) used a very simple model to estimate relative contributions of carbon monoxide sources at different distances. They concluded that about one-fourth of the time, downtown street canyon monitors measured concentrations where more than half of the carbon monoxide came from the local street. The frequency of local traffic dominance increases to more than half of the time for street canyons away from the center of the city. Ludwig and Kealoha's (1975) calculations suggest that the dominance of local sources is, as expected, less pronounced for neighborhood type sites. Sources within 2 km of the monitor contribute more than half the observed concentration on about a quarter of the occasions. Thus, the nearer sources contribute a major portion to neighborhood-scale observations, but not as much as for the middle-scale observations.

The preceding discussion applies to gaseous pollutants whose main sources are at ground level and closely related to traffic. Draftz (1975) has concluded that around 90 percent of the mass collected by Hi-Vol samplers near Chicago streets were minerals and auto exhaust particles; the minerals have been attributed to street dust or local soil. Thus, it appears that urban TSP is analogous to carbon monoxide to the

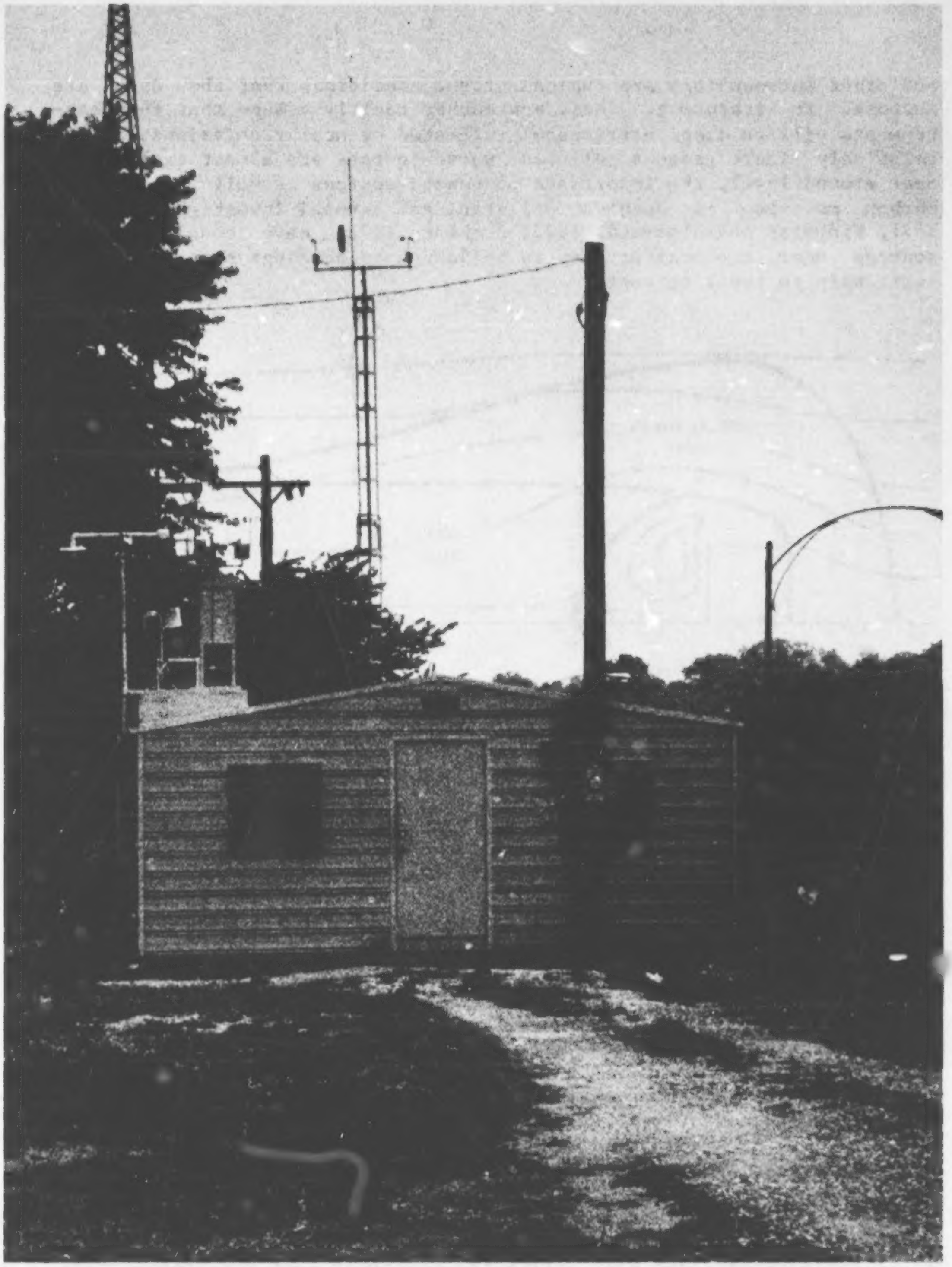

FIGURE 32 HIGH-VOLUME SAMPLER LOCATED ON THE ROOF OF AN INSTRUMENT SHELTER

extent that its ground level sources are traffic dominated. Therefore, observed TSP concentrations should also be dominated by local sources except where major elevated point sources overwhelm the other sources. If we include the effects of the settling of particulates, the dominance of local sources will be reinforced.

Although Draftz (1975) did not measure size distributions of the collected particles, he did indicate that particles with diameters of several tens of microns were found in samples collected near city streets. As we have noted before, only a few such particles are required to equal the mass contained in literally hundreds of thousands of submicron particles. The height to which these particles are raised with their initial injection into the atmosphere will affect the distance that they travel before they settle to the ground again. Cowherd et al. (1974) estimate an average injection height of five feet (150 cm) for dust from unpaved roads. This can be used as a guide to estimate that these larger particles, with settling velocities of one or two cm s^{-1}, are injected at an initial height of 150 to 200 cm. This means that on the average they will remain airborne for a few hundred seconds. At typical wind speeds of a few meters per second these particles will not affect concentrations at distances of much more than a kilometer from their source.

If we return to Ludwig and Kealoha's (1975) estimates of the importance of ground level gaseous sources at various distances from a monitor, we can make some assumptions that will allow us to alter those estimates so that they are more applicable to TSP. From Figures 4 and 5 it appears that about ten to twenty percent of the aerosol mass may be associated with particles that could fall out within about 2 km of their source--particles larger than 5 to 10 μm diameter. If Ludwig and Kealoha's (1975) calculations are adjusted to account for the loss of about ten to twenty percent of the material emitted before it travels more than two kilometers from the source, then it appears that emissions within 2 km of the sampler would account for more than half the observed TSP concentration about 30 to 40 percent of the time.

Of course, all the preceding discussion applies only to areas where the TSP concentrations are not greatly influenced by emissions from elevated point sources. The influence of an elevated point source will depend on emission rates, plume rise, stack height, and distance from the stack With this many variables, it is not possible to give any generalized estimate of elevated point source effects on observed TSP concentrations. However, the Climatological Dispersion Model (CDM) of Busse and Zimmerman (1973) has provisions for separating point source effects from area source effects, and it could be used to evaluate relative contributions for specific cases. Even in those areas where not many contributions come from specific, elevated sources, the model might be applied to ensure that the effect of some point source, or a particularly strong area source, had not been overlooked.

Modeling could also serve to evaluate the appropriateness of emissions control strategies based on data from an existing TSP monitoring site. It could tell if the emissions to be controlled were actually the most important contributions to the observed concentrations. The estimates of the importance of sources at different distances from the sampler support our notion that siting criteria based largely on the distribution of nearby sources will be adequate to define, at least qualitatively, the representativeness of a station that is not intended to be a source-oriented monitor. Once a well located site exists, the argument can be reversed, and we can assume that the data from that site strongly reflect the influence of emissions within its area of representativeness--e.g., a few kilometers for a neighborhood site, a few tens of kilometers for a regional site. Then any control measures that are based on data from that site can be focused on the appropriate area. Obviously, data from source-oriented monitors will be most useful for defining control measures required of the source toward which their monitoring is directed.

Appendix A

MODELING THE POLLUTION CLIMATOLOGY ASSOCIATED WITH STACK EMISSIONS

Appendix A

MODELING THE POLLUTION CLIMATOLOGY ASSOCIATED WITH STACK EMISSIONS

A. Background

The average ground level concentrations of a pollutant and the frequency of occurrence of specified concentrations depend on the characteristics of the sources and on the occurrences of the different atmospheric conditions that transport and dilute the emissions. The heights of the sources and their emission rates are also of great importance. The most influential atmospheric parameters are wind and stability. Wind direction determines where the pollutants will be carried, and wind speed determines the volume of air available for the initial dilution of the pollutants. Atmospheric stability governs the rate of subsequent dilution through turbulent mixing. If a particular pollutant is chemically reactive so that its total mass changes with time, this fact is also important in the determination of expected concentrations. This Appendix provides two simple computer programs, one for estimating average ground-level concentrations, and the other for calculating concentration frequency distributions around an isolated, elevated source. From this information, the most important monitoring locations can be identified.

Diffusion theory provides the basis for a systematic approach to estimating the effects of stack emissions on the environs. That is, the theory can be used to calculate the concentration patterns to be expected during each of some finite number of meteorological conditions. It is thus possible to determine average concentrations and frequency distributions, if the frequency of occurrence of each of the input meteorological conditions is known. This is the approach that has been used here.

B. Description of the Pollution Model

The behavior of pollutants being emitted from a continuous source is commonly described by assuming a Gaussian distribution of concentration within the plume (e.g., Beals, 1971; Smith, 1968; Turner, 1969). For a continuous plume from a smokestack, the distribution of the concentration (C) in space is given by:

$$C = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{h^2}{\sigma_z^2} \right) \right] , \qquad (1)$$

Where

Q is the emission rate of the source (gm s^{-1})
u is the wind speed at stack height (m s^{-1})
σy, σz are the standard deviations of the distribution of concentration in the horizontal and vertical (m)

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y,h are the distances from the center of the plume in the horizontal and vertical (m)

The values of σy and σz depend on the atmospheric stability and the distance downwind of the source. This dependence has been determined from field experiments that have released tracer materials in the atmopshere. Figure A-1 illustrates relationships among σy, and σz, distance from source, and atmospheric stability. These relationships are widely used (e.g., Beals, 1971; Turner, 1969). They were originally published by Cifford (1961), ana they form a basis for some of the inputs to the model described here.

Because the concentrations of interest are those at ground level, the term h in Eq. (1) can be considered the effective height of the source. Gases usually leave a stack with some finite velocity and buoyancy, because they are often warmer than the ambient atmosphere. Therefore, the effective height of the stack is generally higher than the actual height by some increment. This increment, Δh, is determined by the equations below, suggested by Smith (1968).

For stable atmospheric conditions:

$$\Delta h = 2\left(\frac{F}{uG}\right)^{0.33} \qquad (2)$$

For neutral or unstable atmospheric conditions:

$$\Delta h = 150F/u^3 \qquad (3)$$

$$f = g\, V_s\, r_s{}^2 \left(\frac{T_s - T}{T}\right) \text{ is the buoyancy flux} \qquad (4)$$

g is the gravitational acceleration, 9.8 m s^{-2}

T_s is the stack gas temperature at exit (^oK)

T is the ambient air temperature (taken to be 300° K)

V_s is the velocity of the stack gases (m s^{-1}).

The term G relates to the rate of change of temperature with height. For stable atmospheric conditions a value of about 6×10^{-4} is appropriate (see example given by Smith, 1968) and is used with this

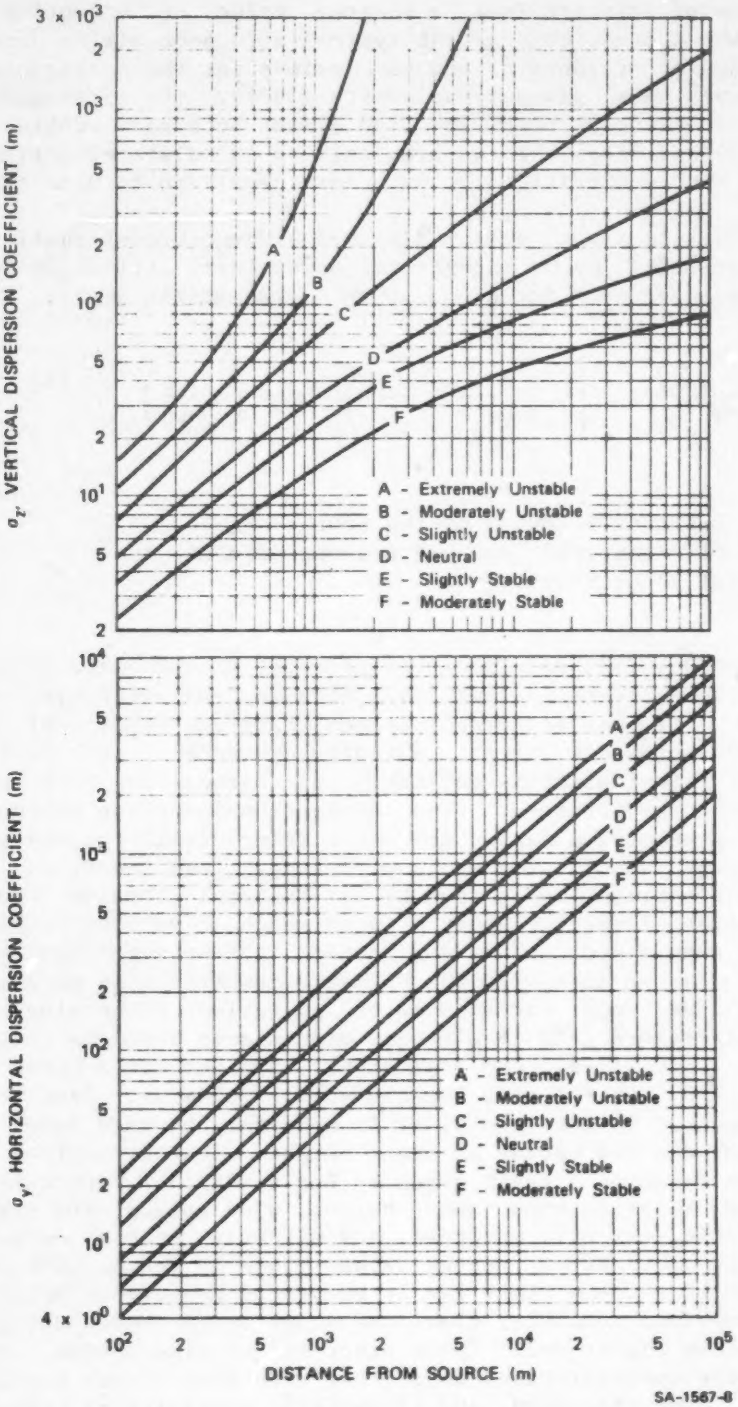

FIGURE A-1 VARIATION OF σ_z AND σ_y WITH DISTANCE AND ATMOSPHERIC STABILITY model. For low wind speeds and neutral or unstable atmospheric conditions, the values of Δh become quite large and unreliable. To minimize the effects of this artifact, a maximum value of effective stack height should be chosen, such as the typical afternoon mixing depths for the area and season of concern. Average values for the contiguous United States have been given by Holzworth (1971). The afternoon values should be used because at night low wind speeds accompany stable atmospheric conditions, and the equation used to calculate effective stack height during stable conditions is much less sensitive to wind speed.

Some pollutants (e.g., sulfur dioxide) undergo transformations that can be approximated by an exponential decay term. Provision for such transformations have been included. With exponential decay, Equation (1) becomes:

$$C = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{h^2}{\sigma_z^2}\right)\right] \exp\left(-\frac{x}{u\tau}\right) , \quad (5)$$

where

x is the distance downwind of the source (m)
τ is the time required for 63.2 percent (1/e) of the material to be transformed.

Equations (2), (3), and (5) are sufficient to calculate ground level concentrations, if the proper stack emission and meteorological data are available. The required meteorological data are atmospheric stability and winds at stack height. Although atmospheric stability is not reported from weather stations routinely, algorithms have been developed to determine this parameter from conventional surface weather data. Turner (1964) presented a method for determining stability; the required inputs are wind speed, the sun's elevation, cloud cover, and ceiling height. Turner's technique is used by the National Climatic Center to prepare summaries of the frequency of occurrence of various combinations of stability, wind speed, and wind direction. These summaries, prepared from hourly weather data with the Climatic Center's STAR program, provide a nearly ideal input for studies of pollution climatology. Wind directions are divided into 16 classes, wind speeds into six classes (< 3, 4-6, 7-10, 11-16, 17-21, and > 21 knots), and the atmospheric stabilities into five (or for some locations, six) classes. Since the wind speeds are measured at low levels, it is necessary to make some correction to approximate the speeds at stack height. The corrections used in the model were based on a graph given by Beals (1971). Figure A-2 shows his suggested relationships among height, wind speeds, and stability; the very unstable, slightly unstable, and slightly stable curves have been added to the three curves values given by Beals. The midrange value for each wind speed class can be converted to a stack height value for the appropriate stability class and input to the model using a factor obtained from Figure A-2. These stack-height wind speeds are used to calculate the concentrations associated with each of the combinations of wind speed, wind direction, and atmospheric stability represented in the STAR program output.

Certain simplifications have been made to permit the use of polar coordinates and to reduce the computational complexity. The model has provided for treating two stacks; both are assumed to be at the origin of the polar coordinate system. This simplification is justifiable if the distance between the stacks is small compared with the downwind dis-

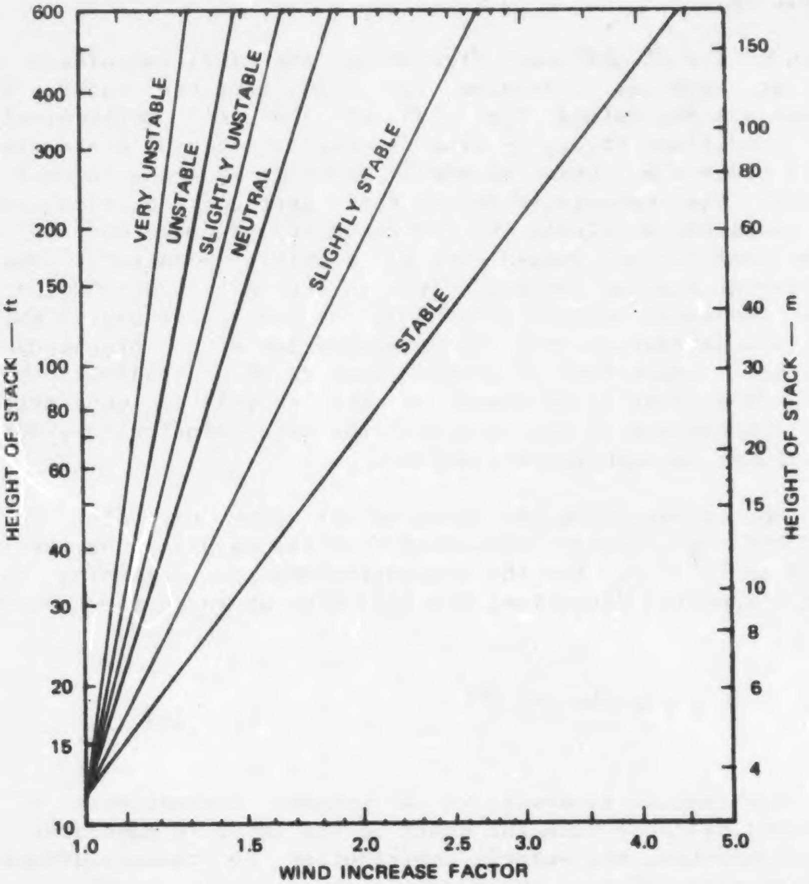

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FIGURE A-2 VARIATION OF WIND SPEED WITH HEIGHT AND ATMOSPHERIC STABILITY tances to areas where higher ground level concentrations are expected to occur. One stack is assumed to have relatively constant emission characteristics. The second can have three different levels of emissions.

The fraction of the time spent by the variable stack in each operating mode can be specified. It is assumed that the different operations have no meteorological bias, i.e., that the likelihood of the stack being in a particular operating mode is the same for all meteorological conditions.

For each of the 16 different directions, the model calculates concentrations at numerous distances (up to 40) from the stacks. These concentrations are determined for each of the 1440 meteorological-operational conditions (i.e., 16 wind directions x 6 wind speed classes x 5 stability classes x 3 stack operating modes). In one version of the model (POLAVE) the calculated values for a particular meteorological-operational class are multiplied by the frequency of occurrence of that class; these products are summed over all possible operational combinations to determine average concentrations in the area surrounding the stacks. In the other version (POLFREQ), the concentrations calculated by the model are categorized for the determination of the frequency that various critical concentration levels (such as standards) might be exceeded. This determination is based on the calculated concentration values and the frequency of occurrence of the meteorological-operational conditions leading to such concentrations.

The concentrations along the plume center line extending in the downwind direction are easily calculated from the equations by setting y equal to zero in Eq. (5). For the concentrations on adjoining radii, 22.5° from the downwind direction, the following approximation is used:

$$y = x \sin (22.5^\circ) \ . \qquad (6)$$

In essence, this results in about an 8 percent overestimate of the downwind travel distance from the stack to the point in question. From a practical standpoint, the stack's contribution to concentrations at locations more then 45° from the downwind direction is essentially zero and is so considered by the model for determining the frequency with which various critical concentration values might be exceeded. For determining average concentrations, the concentrations at points 45° or more from the downwind direction were all assumed to be the same, and to be equal to the value obtained from Eq. (5), using the downwind distance x and a value of y equal to x sin (45°).

C. Computer Programs

The computer program for computing average pollution concentrations around an elevated source is called POLAVE, while that for computing frequency distributions of concentration around an elevated source is called POLFREQ. A subroutine called STCKHT is used with both of these programs to calculate plume rise. The FORTRAN variables and the input requirements are identical for both programs. Table A-1 defines the variables used in the programs; Table A-2 describes the inputs required to operate either of the programs. The data that are read into the computer consist of: (1) mixing depth and categorized values of variables derived from Figures A-1 and A-2; (2) stack height and diameter, emission rate, gas temperature, and pollutant concentration in the stack gas--for both a constant and a variable source; and (3) frequency distributions at the site for all combinations of stability, wind direction, and wind speed. These data provide the necessary information for computing either the average or the frequency distribution of pollutant concentrations about an isolated elevated source, using either POLAVE or POLFREQ. A listing for these two programs and subroutine STCKHT follows Table A-2.

Table A-1

FORTRAN VARIABLES USED IN THE PROGRAMS POLFREQ AND POLAVE

CL = Concentration on plume axis and at two distances off axis ($g\ m^{-3}$)

DEC = Provision for decay--currently set to be negligible (sec)

D1,D2 = Stack diameter (m) for constant and variable source

FRACT = Time spent in each of the three different operating conditions of the variable source (percent)

FREQ = Frequency of occurrence of various categorical combinations of stability, wind direction, and speed (percent)

F1,F2 = Emission rate (scfm) for constant and variable sources

SEASON = Season or annual identifiers (alphanumeric)

HNUM = Mixing depth (m)

ID = Wind direction category index

ISP = Wind speed index

IX = Distance index

R = Radial distance (m)

PCT1,PCT2 = Stack gas pollutant concentration ($g\ ft^{-3}$) for constant and variable source

STAND = Lower limits on concentration categories for frequency calculations ($g\ m^{-3}$)

SUM F = Frequency of occurrence (POLFREQ) or averages (POLAVE) of various concentration categories for the different distance and direction categories (percent)

Table A-1 (continued)

SY,SZ = Horizontal and vertical standard deviations of plume concentration (m)

T1,T2 = Stack gas temperature for constant and variable source (°F)

WS = Wind speed (m s^{-1})

Table A-2

INPUT PARAMETERS FOR THE PROGRAM POLFREQ AND POLAVE

CARD NUMBER	VARIABLES	FORMAT	COLUMNS	REMARKS
1-5	IST	1X,I2	2-3	Stability category index (total number of categories 5 or 6; 5 used in listing given here)
	WS values for 6 speed classes on one card, cards for 5 (or 6) stability classes	6F6.2	4-39	Wind speeds at stack height for different surface wind speed and stability categories (m/s). Obtain from Figure A-2 and STAR program categories.
6-45	IX	I2	1-2	Distance index (total number of distance values to be specified by user is 40).
	R; one distance value per card.	F6.0	3-8	Radial distance (m)
	SZ values for 5 (6) stability classes on one card, cards for 40 distance values.	F6.0	3-8	Standard deviation of plume concentration in vertical (m). Obtain from Figure A-1. If 5 stability categories are used (as here), then last field is not used.
	SY values for 6 stability classes on one card, cards for 40 distance values.	6F6.0	45-80	Standard deviation of plume concentration in horizontal (m); see comment for SZ.

Table A-2 (continued)

CARD NUMBER	VARIABLES	FORMAT	COLUMNS	REMARKS
46	F1	E8.1	1-8	Emission rate (SCFM) for constant source.
	T1	E8.1	9-16	Gas temperature (°F) for constant source.
	PCT1	F8.1	17-26	Pollutant concentration (g/standard ft^3).
	D1	F8.1	25-32	Stack diameter (m) for constant source.
	H11	F8.1	33-40	Stack height (m) for constant source.
	D2	F8.1	41-48	Stack diameter (m) for variable source.
	H22	F8.1	49-56	Stack height (m) for variable source.
47-49	F2	E8.1	1-8	Emission rates (SCFM) for variable source, one card for each of three operating conditions.
	T2	F8.1	9-16	Gas temperature (°F) for variable source.
	PCT2	F8.1	17-24	Pollutant concentrations (g/ft^3) for variable source.
	FRACT	F8.1	25-32	Time (percent) spent in each of the three operating conditions of the variable source.

Table A-2 (concluded)

CARD NUMBER	VARIABLES	FORMAT	COLUMNS	REMARKS
50	SEASON	A10	1-10	Season or annual identifier.
	HNUM	F10.1	11-20	Afternoon mixing depth (m).
51-130	IST	1X,I4	2-5	IST is the stability class. There are 80 cards, 16 wind directions and 5 stability classes. If six stability classes are used, there will be 96 cards.
	FREQ, values for 6 stability classes on one card, cards for all possible combinations of wind direction and speed classes.	6F7.5	11-2	Frequency of occurrence of various categorical combinations of stability, wind direction, and speed (percent).

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LIST OF PROGRAMS

```
      PROGRAM POLFREQ (INPUT.OUTPUT)
C**********
C**********THIS PROGRAM CALCULATES FREQUENCY DISTRIBUTIONS OF
P**********CONCENTRATIONS AROUND STACKS USING GAUSSIAN PLUME FORMULA.
C**********
      COMMON /A/ FS1.FS2(3).H1.H2(3).U.IST.ISP.H11.H22.D11.D22.HNUM
      DIMENSION NC(3).VS2(3).Q2(3).FRACT(3).FREQ(6.16.6).WS(6.6).SZ(6.40
     1).SY(6.40).R(40).HZ2(3).SUMF(40.16.10).F2(3).T2(3).PCT2(3).IJ(9)
     2.XXX(3).STAND(6)
C**********
P**********STAND=CONCENTRATION CATEGORIES (GM/CU.M)
C**********
      DATA (STAND=0.0.2.5E-4.3.65E-4.8.5E-4.1.3E-3.1.0)
      DATA (XXX=0.0.0.3827.0.707.)
      DATA (IJ = -10,-9,-8,-7,-6,-5,-4,-3,-2)
C**********
C**********THROUGH STATEMENT 23 VARIOUS DATA ARE READ AND UNITS ARE
C**********CONVERTED.
C**********
C**********INITIALLY - READ WIND SPEED AT STACK HT. FOR DIFFERENT SPEED
 **********(ISP) AND STABILITY (IST) CATEGORIES. THIS IS A TABLE BASED
 **********ON FIG 2 OF APPENDIX. STACK-HEIGHT WINDS ARE ENTERED FOR EACH
 **********STABILITY CLASS AND EACH WIND SPEED CLASS USED BY STAR
 **********PROGRAM (M/S). 6 CARDS
C**********
      DO 19 I=1.6
      READ 10.IST.(WS(IST.ISP).ISP=1.6)
 19   CONTINUE
C**********
C**********READ DISTANCES (R) AND CORRESPONDING STANDARD DEVIATION
C**********VALUES (SZ.SY) TO BE USED IN SUBSEQUENT CALCULATIONS. SIGMAS
C**********TAKEN FROM FIG 1. FOR RADIAL DISTANCES CHOSEN BY USER. ALL
C**********UNITS IN METERS. 40 CARDS
C**********
      DO 20 I=1.40
      READ 14.IX.R(IX).(SZ(IS.IX).IS=1.6).(SY(IS.IX).IS=1.6)
 20   CONTINUE
C**********
C**********READ FLOW (SCFM). GAS TEMPERATURE (DEG. F). POLLUTANT
C**********CONCENTRATION (GM/CU.FT). ID (FT). HT (FT) FOR CONSTANT
C**********SOURCE. AND ID (FT). HT. (FT) FOR VARIABLE SOURCE.
C**********
      READ 7.F1.T1.PCT1.D1.H11.D2.H22
C**********
C**********CONVERTING TO METRIC UNITS AND GETTING VALUES FOR PLUME RISE
C**********CALCULATIONS.
C**********
      Q1=0.017*F1*PCT1 $ D1=0.305*D1 $ H11=0.305*H11 $ D2=0.305*D2
      T1=0.5556*(T1-32.0)+273.0 $ H22=0.305*H22
      VS1=1.1*4.72E-4*F1*T1/(293.0*0.785*D1*D1)
C**********
C**********READ FLOW (SCFM). GAS TEMPERATURE (DEG. F). POLLUTANT
C**********CONCENTRATION (GM/CU.FT). TIME SPENT IN OPERATING CONDITION
C**********(PCT) FOR EACH OF 3 OPERATING CONDITIONS ON VARIABLE STACK.
C**********3 CARDS
C**********
C**********
      DO 22 I=1.3
      READ 7.F2(I).T2(I).PCT2(I).FRACT(I)
C**********
C**********CONVERTING TO METRIC UNITS AND GETTING VALUES FOR PLUME RISE
C**********CALCULATIONS.
C**********
      Q2(I)=0.017*F2(I)*PCT2(I)
      T2(I)=0.5556*(T2(I)-32.0)+273.0
      VS2(I)=1.1*4.72E-4*F2(I)*T2(I)/(293.0*0.785*D2*D2)
      FRACT(I)=0.01*FRACT(I)
 22   CONTINUE
```

```
C***********
C***********READ SEASON (OR ANNUAL) IDENTIFIER AND MIX DEPTH (M).
C***********
      READ 1.SEASUN.HNUM
      DO 23 I=1.80
C***********
C***********SHOULD BE I=1.96 FOR 6 STABILITY CLASSES.
C***********READ FREQ CF OCCURRENCE OF COMBINATIONS OF STABILITY (IST).
C***********WIND DIRECTION (ID). AND SPEED CLASS (IJ).
C***********
      READ 6.IST.ID.(FREQ(IST.ID.J).J=1.6)
 23   CONTINUE
C***********
C***********DEC=PROVISION FCR DECAY - SET TO BE NEGLIGIBLE.
C***********CALCULATING PARMETERS FOR PLUME RISE-ASSUMES AMBIENT TEMT OF
C***********300 DEG K.
C***********
      DEC=6.00E6 $FS1=D1*2.45*VS1*D1*( T1-300.0)/300.0
C***********
C***********SETTING INITIAL VALUES OF FREQUENCIES =0.
C***********
      CALL MEMSET (0.0.SUMF.6400)
C***********
C***********CALCULATING PARMETERS FOR PLUME RISE-ASSUMES AMBIENT TEMP OF
C***********300 DEG K.
C***********
      DO 30 I=1.3
      FS2(I)=2.45*VS2(I)*D2*D2*( T2(I)- 300.0)/300.0
 30   CONTINUE
C***********
C***********THE LOOPS THROUGH STATEMENT 900 CALCULATE CONCENTRATIONS FOR
C***********VARIOUS STABILITIES (IST). WIND SPEEDS (ISP). DISTANCES FROM
C***********STACK (IX).  AND THE OPERATING CONDITIONS (NOP). OCCURRENCE
C***********FREQUENCY IN DIFFERENT CONCENTRATION INTERVALS ARE DETERMINED
C***********AND SUMMED.
 ***********
      DO 900 IST=1.5
C***********
C***********SHOULD BE IST=1.6 FOR 6 STABILITY CLASSES.
C***********
      DO 900 ISP=1.6
C***********
C***********CORRECTING WIND SPEED TO STACK HEIGHT.
C***********
      U = WS(IST.ISP) $ UPI=3.1416*U
C***********
C***********CALL STCKHT TO CLACULATE PLUME HT.
C***********
      CALL STCKHT
      DO 900 IX=1.30
      SZDAT=SZ(IST.IX) $ SYDAT=SY(IST.IX)
      SZ2=SZDAT*SZDAT $ SY2=SYDAT*SYDAT
C***********
C***********DETERMINING VALUES OF VARIOLS FACTORS NECESSARY TO CALCULATE
C***********CONCENTRATIONS.
C***********
      X=R(IX) $ T=X/U
      DECAY=EXP(-T/DEC)
      COEF=DECAY/(UPI*SZDAT*SYDAT) $ Q1COEF =Q1*COEF
      HZ1=0.5*H1*H1/SZ2
      DO 900 NOP=1.3
      HZ2(NOP)=0.5*H2(NOP)*H2(NOP)/SZ2
C***********
C***********DETERMINING CONCENTRATION (CLC) ON PLUME AXIS AND AT 2 DIST-
C***********ANCES (Y) OFF AXIS.
C***********
      DO 600 J=1.3
      IF(J.NE.3) GO TO 510
```

```
C***********
C***********FOR 45 OR MORE DEG. OFF CENTER LINE, CONCENTRATION IS ASSUMED
C***********TO FALL IN THE LOWEST CONCENTRATION CATEGORY (NCLC=1).
C***********
      NCLC = 1 $ GO TO 560
  510 Y = X*XXX(J) $ Y2 = 0.5*Y*Y/SY2
      C1=Q1COEF*EXP(-HZ1-Y2)
      C2=Q2(NUP)*COEF*EXP(-HZ2(NUP)-Y2)
      CLC = C1+C2
C***********
C***********SPECIFYING CONCENTRATION CATEGORY FOR CENTERLINE AND +/- 22.5
C***********DEG.
C***********
 540  DO 555 JJJ=1,6
      IF (CLC.GE.STAND(JJJ)) NCLC = JJJ
 555  CONTINUE
 560  NC(J)=NCLC
 600  CONTINUE
      DO 900 ID=1,16
C***********
C***********FRAFRE = FREQ OF OCCURRENCE OF COMBINATIONS OF STABILITY,
C***********WIND DIRECTION AND SPEED, AND PLANT OPERATING CONDITIONS.
C***********
      FRAFRE=FRACT(NOP)*FREQ(IST,ID,ISP)
      IF(FREQ(IST,ID,ISP).EQ.0.0) GO TO 900
      DO 900 J1=1,16
      IF(J1.EQ.1.OR.J1.EQ.15) GO TO 610
      IF(J1.EQ.16) GO TO 605
      J=3 $ GO TO 615
  605 J=1 $ GO TO 615
  610 J=2
  615 JD=ID+J1+7
      JD=MOD(JD,16)
      IF (JD .EQ. 0)  JD = 16
      N1=NC(J)
C***********
C***********ACCUMULATING FREQUENCIES FOR DIFFERENT LOCATIONS.
C***********
      DO 900 MCUM=1,N1
      SUMF(IX,JD,MCUM) = SUMF(IX,JD,MCUM) + FRAFRE
  900 CONTINUE
C***********
C***********THROUGH STATEMENT 950 FREQUENCIES ARE PRINTED.
C***********
      DO 950 ID=1,16
      DI = ID $ DI = 22.5*DI
      PRINT 3,DI,SEASON,HNUM $ PRINT 9
      PRINT 11,(STAND(JJJ),JJJ=1,6)
      DO 950 IX=1,30
      PRINT 5,R(IX),(SUMF(IX,ID,MC), MC = 1,6)
  950 CONTINUE
    1 FORMAT (A10,F10.1)
    3 FORMAT (1H0 , *DIRECTION FROM SMELTER =*,F6.1,*DEGREES*,10X,
     1A10,10X*MIXING HT. =*F10.1/)
    5 FORMAT  (1H ,E15.3,6F14.6)
    6 FORMAT (1X,I4,I5,6F7.5,)
    7 FORMAT (E8.1, 6F8.1)
    8 FORMAT (4F8.1)
    9 FORMAT (/50X, *CUMULATIVE FREQUENCIES - GM./CU. M*)
   10 FORMAT (1X,I2,6F6.2)
   11 FORMAT (7X,*DISTANCE M*4X*TOTAL*,3X,6(*GT*   ,E7.1,2X))
   14 FORMAT (I2,13F6.0)
   16 FORMAT (3F9.2,2E9.1)
      STOP
      END
      PROGRAM PULAVE  (INPUT,OUTPUT)
C***********
C***********CALCULATES AVERAGE POLLUTANT CONCENTRATIONS AROUND STACKS
C***********USING GAUSSIAN FORMULAE.
C***********
      COMMON /A/ FS1,FS2(3),H1,H2(3),U,IST,ISP,H11,H22,D11,D22,HNUM
      DIMENSION       VS2(3),Q2(3),FRACT(3),FREQ(6,16,6),WS(6,6),SZ(6,40
     1),SY(6,40),R(40),H22(3),SUMF(40,16,10),F2(3),T2(3),PCT2(3),IJ(9)
     2,XXX(3),XXNC(3)
      DATA (XXX=0.0,0.3827,0.7071)
      DATA (IJ = -10,-9,-8,-7,-6,-5,-4,-3,-2)
C***********
C***********THROUGH STATEMENT 23 VARIOUS DATA ARE READ AND UNITS ARE
C***********CONVERTED.
C***********
C***********INITIALLY - READ WIND SPEED AT STACK HT. FOR DIFFERENT SPEED
C***********(ISP) AND STABILITY (IST) CATEGORIES.
C***********
      DO 19 I=1,6
      READ 10,IST,(WS(IST,ISP),ISP=1,6)
 19   CONTINUE
C***********
C***********READ DISTANCES (R) AND CORRESPONDING STANDARD DEVIATION
C***********VALUES (SZ,SY) TO BE USED IN SUBSEQUENT CALCULATIONS.
C***********
      DO 20 I=1,40
      READ 14,IX,R(IX),(SZ(IS,IX),IS=1,6),(SY(IS,IX),IS=1,6)
 20   CONTINUE
C***********
C***********READ FLOW (SCFM), GAS TEMPERATURE (DEG. F), POLLUTANT CONCEN-
C***********TRATION (GM/CU. FT.), ID (FT), HT (FT) FOR CONSTANT SOURCE
C***********AND ID (FT), AND HT. (FT) FOR VARIABLE SOURCE.
C***********
      READ 7,F1,T1,PCT1,D1,H11,D2,H22
C***********
C***********CONVERTING TO METRIC UNITS.
C***********
      Q1=0.017*F1*PCT1 $ D1=0.305*D1 $ H11=0.305*H11 $ D2=0.305*D2
      T1=0.5556*(T1-32.0)+273.0 $ H22=0.305*H22
      VS1=1.1*4.72E-4*F1*T1/(293.0*0.785*D1*D1)
C***********
C***********READ (FOR VAR. SOURCE OPER. COND., I), FLOW (SCFM), TEMP.
C***********(DEG. F), POLLUTANT CONCENTRATION (GM/CU.FT), TIME SPENT IN
C***********OPERATING CONDITION (PCT).
C***********
      DO 22 I=1,3
      READ 7,F2(I),T2(I),PCT2(I),FRACT(I)
C***********
C***********CONVERTING TO METRIC UNITS.
C***********
      Q2(I)=0.013*F2(I)*PCT2(I)
      T2(I)=0.5556*(T2(I)-32.0)+273.0
      VS2(I)=1.1*4.72E-4*F2(I)*T2(I)/(293.0*0.785*D2*D2)
      FRACT(I)=0.01*FRACT(I)
 22   CONTINUE
C***********
C***********READ SEASON IDENTIFIER AND AVERAGE P. M. MIXING HT.
C***********
      READ 1,SEASON,HNUM
      DO 23 I=1,80
C***********
C***********SHOULD BE I=1,96 FOR 6 STABILITY CLASSES.
C***********READ FREQ OF OCCURRENCE OF COMBINATIONS OF STABILITY (IST),
C***********WIND DIRECTION (ID), AND SPEED CLASS (IJ).
C***********
      READ 6,IST,ID,(FREQ(IST,ID,J),J=1,6)
 23   CONTINUE
      DEC=6.00E4 $FS1=D1*2.45*VS1*D1*( T1-300.0)/300.0
C***********
C***********SETTING INITIAL VALUES OF FREQUENCIES =0.
C***********
      CALL MEMSET (0.0,SUMF,6400)
      DO 30 I=1,3
      FS2(I)=2.45*VS2(I)*D2*D2*( T2(I)- 300.0)/300.0
 30   CONTINUE
```

```
C***********
C***********THE LOOPS THROUGH STATEMENT 900 CALCULATE CONCENTRATIONS FOR
C***********VARIOUS STABILITIES (IST). WIND SPEEDS (ISP). DISTANCES FROM
C***********STACK (IX) AND PLANT OPERATING CONDITIONS (NOP).
C***********
      DC 900 IST=1.5
C***********
C***********SHOULD BE IST=1.6 FOR 6 STABILITY CLASSES.
C***********
      DO 900 ISP=1.6
      U = WS(IST.ISP) $ UPI=3.1416*U
C***********
C***********CORRECTING WIND SPEED TO STACK HEIGHT.
C***********
      CALL STCKHT
      DO 900 IX=2.36
      MMM = MOD(IX.2)
      IF (IX .LT. 28 .AND. MMM.GT. 0 ) GO TC 900
      SZDAT=SZ(IST.IX) $ SYDAT=SY(IST.IX)
      SZ2=SZDAT*SZDAT $ SY2=SYDAT*SYDAT
C***********
C***********DETERMINING VALUES OF VARIOJS FACTORS NECESSARY TO CALCULATE
C***********CONCENTRATIONS.
C***********
      X=R(IX) $ T=X/U
      DECAY=EXP(-T/DEC)
      COEF=DECAY/(UPI*SZDAT*SYDAT) $ Q1COEF =Q1*COEF
      HZ1=0.5*H1*H1/SZ2
      DO 900 NOP=1.3
      HZ2(NOP)=0.5*H2(NOP)*H2(NOP)/SZ2
C***********
C***********DETERMINING CONCENTRATION (CLC) ON PLUME AXIS AND AT 2 DIST-
C***********ANCES (Y) OFF AXIS.
C***********
      DO 600 J=1.3
      Y=X*XXX(J)
      Y2=0.5*Y*Y/SY2
      C1=Q1COEF*EXP(-HZ1-Y2)
      C2=Q2(NOP)*COEF*EXP(-HZ2(NOP)-Y2)
      CLC = C1+C2 $ XXNC(J)=CLC
 600  CONTINUE
      DO 900 ID=1.16
C***********
C***********FRAFRE = FREQ. OF OCCURRENCE OF COMBINATIONS OF STABILITY.
C***********WIND DIRECTION AND SPEEC. AND PLANT OPERATING CONDITIONS.
C***********
      IF(FREQ(IST.ID.ISP).EQ.0.0) GO TO 900
      FRAFRE=FRACT(NOP)*FREQ(IST.ID.ISP)
      DO 900 J1=1.16
      IF(J1.EQ.1.CR.J1.EQ.15) GO TO 610
      IF(J1.EQ.16) GO TO 605
      J=3 $ GO TO 615
  605 J=1 $ GO TO 615
  610 J=2
  615 JD=ID+J1+7
      JD=MOD(JD.16)
      IF (JD .EQ. 0)  JD = 16
C***********
C***********ACCUMULATING COMPONENTS OF AVER. CONCENTRATION FROM EACH
C***********CATEGORY OF STABILITY. WIND SPD. AND WIND DIR.
C***********
      SUMF(IX.JD.1)=SUMF(IX.JD.1)+FRAFRE*XXNC(J)
  900 CONTINUE
```

```
C**********
C**********THROUGH STATEMENT 950 AVERAGES ARE PRINTED.
C**********
      DO 950 ID=1.16
      DI = ID $ DI = 22.5*DI
      PRINT 3.DI.SEASON.HNUM $ PRINT 9
      PRINT 11
      DO 950 IX=2,36
      MMM = MOD(IX.2)
      IF (IX .LT. 28 .AND. MMM.GT. 0 ) GO TO 950
      PRINT 5.R(IX), SUMF(IX,ID,1)

950 CONTINUE
  1 FORMAT (A10,F10.1)
  3 FORMAT (1H0 , *DIRECTION FROM SMELTER =*,F6.1,*DEGREES*, 10X,
   1A10,10X*MIXING HT. =*F10.1/)
  5 FORMAT  (1H ,2E15.3)
  6 FORMAT (1X,I4,I5,6F7.5,)
  7 FORMAT (E8.1, 6F8.1)
  8 FORMAT (4F8.1)
  9 FORMAT (/50X, *AVERAGE CONCENTRATIONS - GM./CU. M*)
 10 FORMAT (1X,I2,6F6.2)
 11 FORMAT (7X,*DISTANCE M*9X*AVERAGE*)
 14 FORMAT (I2,13F6.0)
 16 FORMAT (3F9.2,2E9.1)
    STOP
    END
```

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```
      SUBROUTINE STCKHT
C***********
C***********THIS ROUTINE CALCULATES EFFECTIVE STACK HEIGHT
C***********HNUM = MAX ALLOWABLE EFFECTIVE STACK HT. (M). USING AVERAGE
C***********P. M. MIXING DEPTH.
C***********
      COMMON /A/ FS1.FS2(3).H1.H2(3).U.IST.ISP.H11.H22.D11.D22.HNUM
      IF (IST.LT.5) GO TO 440
      G = 5.9E-4
      H1= H11    +2.0 *((FS1/(U*G))**0.33)
      IF(H1.GT.HNUM) H1=HNUM
      DO 410 NOP=1.3
      H2(NOP)=H22+2.0 *((FS2(NOP)/(U*G))**0.33)
      IF (H2(NOP).GT.HNUM) H2(NOP)=HNUM
  410 CONTINUE
      GO TO 450
  440 H1=H11  +(150.0*FS1/(U*U*U ))
      IF (H1.GT.HNUM) H1=HNUM
  443 DO 450 NOP=1.3
      H2(NOP)=H22    + (150.0*FS2(NOP)/(U*U*U))
      IF (H2(NOP).GT.HNUM) H2(NOP)=HNUM
  450 CONTINUE
      RETURN
      END
```

Appendix B

BIBLIOGRAPHY

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Appendix B

BIBLIOGRAPHY

A literature review has provided a collection of papers and reports on topics related to the measurement and distribution of TSP concentrations. The bibliography is arranged alphabetically by author and numbered consecutively. Each item in the bibliography has been classified into the categories shown in Table B (see Section III of the text). The resulting matrix is given in Table B-1. The bibliography item number is entered in all the applicable categories. Some of the more comprehensive reports may be tallied in several categories. Table B-1 can be easily used to determine which of the reports in the bibliography are related to the various sampling purposes and scales of measurement.

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Table B-1

LIBRARY INDEX, ARRANGED ACCORDING TO MEASUREMENT PURPOSES AND SCALES
(Numbers in Columns Refer to Numbers by Which Entries are
Cataloged in the Bibliography)

Purpose for Which Data Are To Be Used	Not Related to Scale	Applicable Scale of Measurement						Source Oriented	
		Regional		Neighborhood		Middle			
		Respirable	Total	Respirable	Total	Street Canyon	Traffic Corridor	Elevated	Surface
1. Determine compliance with standards	2 74 53 97		53 74		53			120	120
2. Provide data for environmental impact statements	4		4	4	144				
3. Evaluate impact of specific sources	98		37 77 51 107 76		22 56 48 68 51 69 55 76	22 51	98	19 69 80	19 44 69 80
4. Determine environmental effects	72	41	65	41					
5. Provide basis for describing processes that affect particulate concentration	7 47 9 52 10 70 31 89 33 94 34 134 43 135		37 78 112 51 79 116 52 95 120 58 103 136 63 106 143 65 107 148 70 108 76 109 77 110		7 79 22 95 48 108 51 109 55 116 58 136 63 143 71 144 76 148 78	10 22 32 51 137 143	6	19 126 140 141	19 77 32 126 33 140 34 141 44 52 71
6. Provide basis for evaluating control measures	7 15 39 53	62	53 75 60 82 63 100 74	35 62	7 74 53 75 60 82 63 122 68	82	82	29	29
7. Determine trends	27		23 27 130 24 80 131 25 103 26 116	35	67 85 115				
8. Evaluate effects on human exposure	7 62 10 97 36 118 61 138	129	5 117 129	3 35 129 138 146	5 7 48 117 129	3 10 117	3		
9. Evaluation effects on vegetation	117		5		5				
10. Tests of methods and equipment	1 50 90 7 54 91 8 57 101 13 59 106 14 64 111 21 67 113 34 71 114 40 81 142 46 83 49 84		17 109	127 141	17 109 124 126			19	19 36
11. Assess representativeness of existing monitoring sites	16 30 28 66 121 128 147		18 128 20 132 77 133 86 136 95 147 96 121		11 89 16 95 18 96 20 99 45 121 55 124 56 132 85 133 86 136	18 85	18 85		77 99
12. Miscellaneous	12 87 115 28 88 123 30 91 125 33 97 139 38 101 145 42 102							19	19 33

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